

Sustainable Electrical Energy Systems (SEES)

Mark O'Malley

LBNL, California

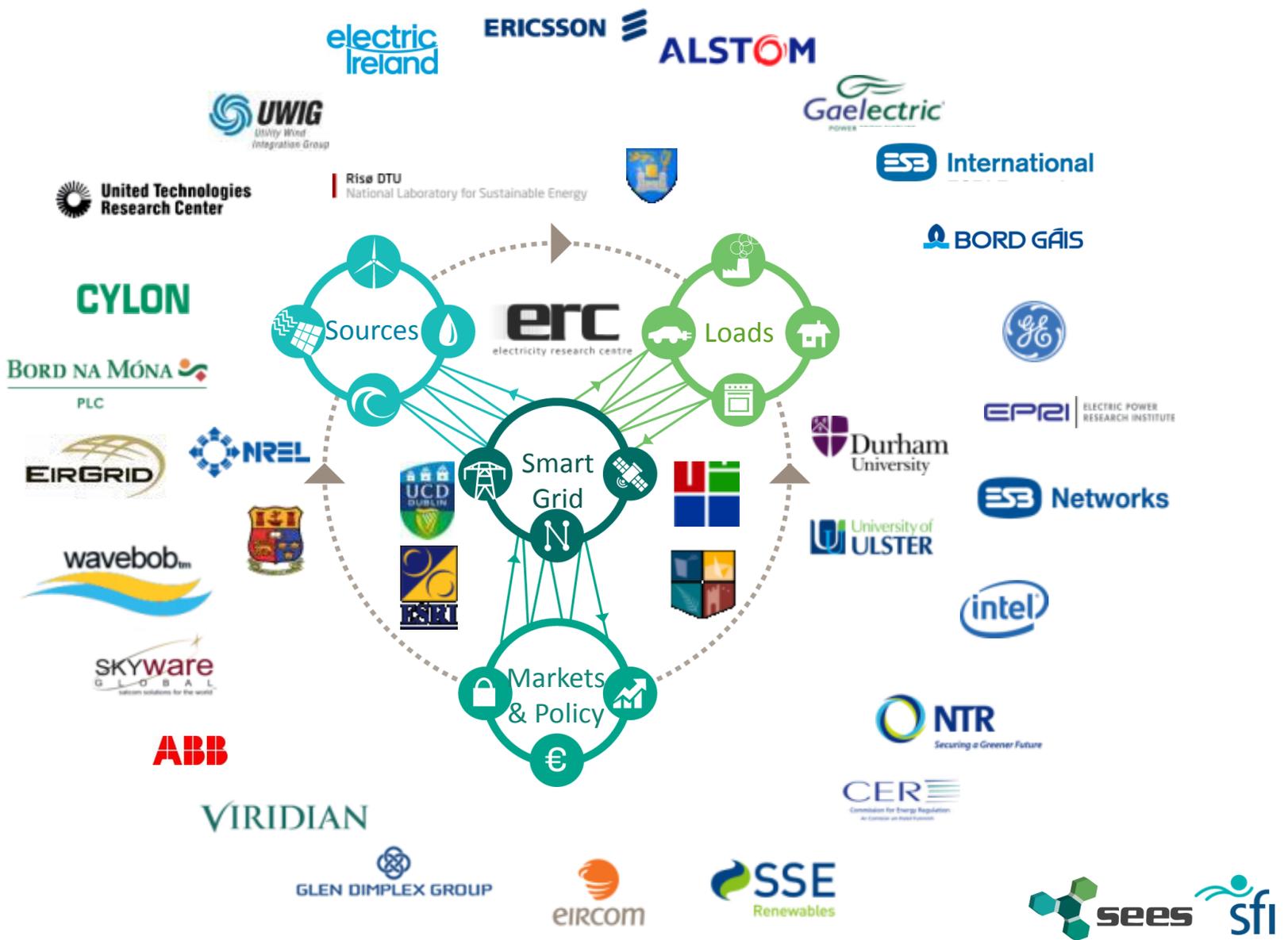
June 27th, 2012



www.ucd.ie/erc



SEES Cluster Overview (2011 – 2016)



HIGH LEVEL OBJECTIVES

DEVELOP STRUCTURE TO DELIVER A
FLEXIBLE & INTEGRATED GRID



DEFINE MARKET POLICY
& FRAMEWORK

IMPLEMENT ICT &
DEMONSTRATIONS

FLEXIBILITY

- WP1 Frequency Stability
- WP2 Voltage Support Requirements
- WP3 Flexibility Metrics



CONTROL

- WP4 Control of Distributed Energy Resources
- WP5 Power System Operations & Control
- WP6 Distributed Control



LOADS & STORAGE

- WP7 Heat Load
- WP8 Storage (large scale, electric vehicle & distributed)
- WP9 Stochastic Processes & Optimisation



ELECTRICITY MARKETS & POLICY

- WP10 Markets & Regulation
- WP11 Demand Side Management



ICT & DEMONSTRATIONS

- WP12* Demonstration Platform



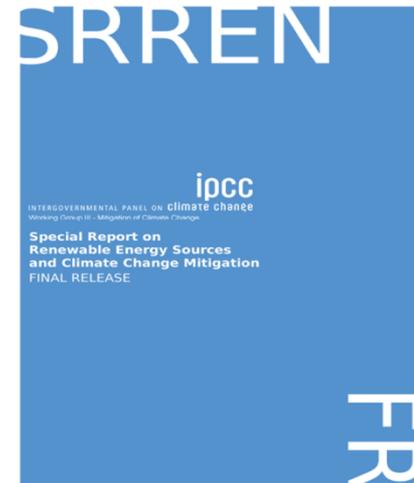
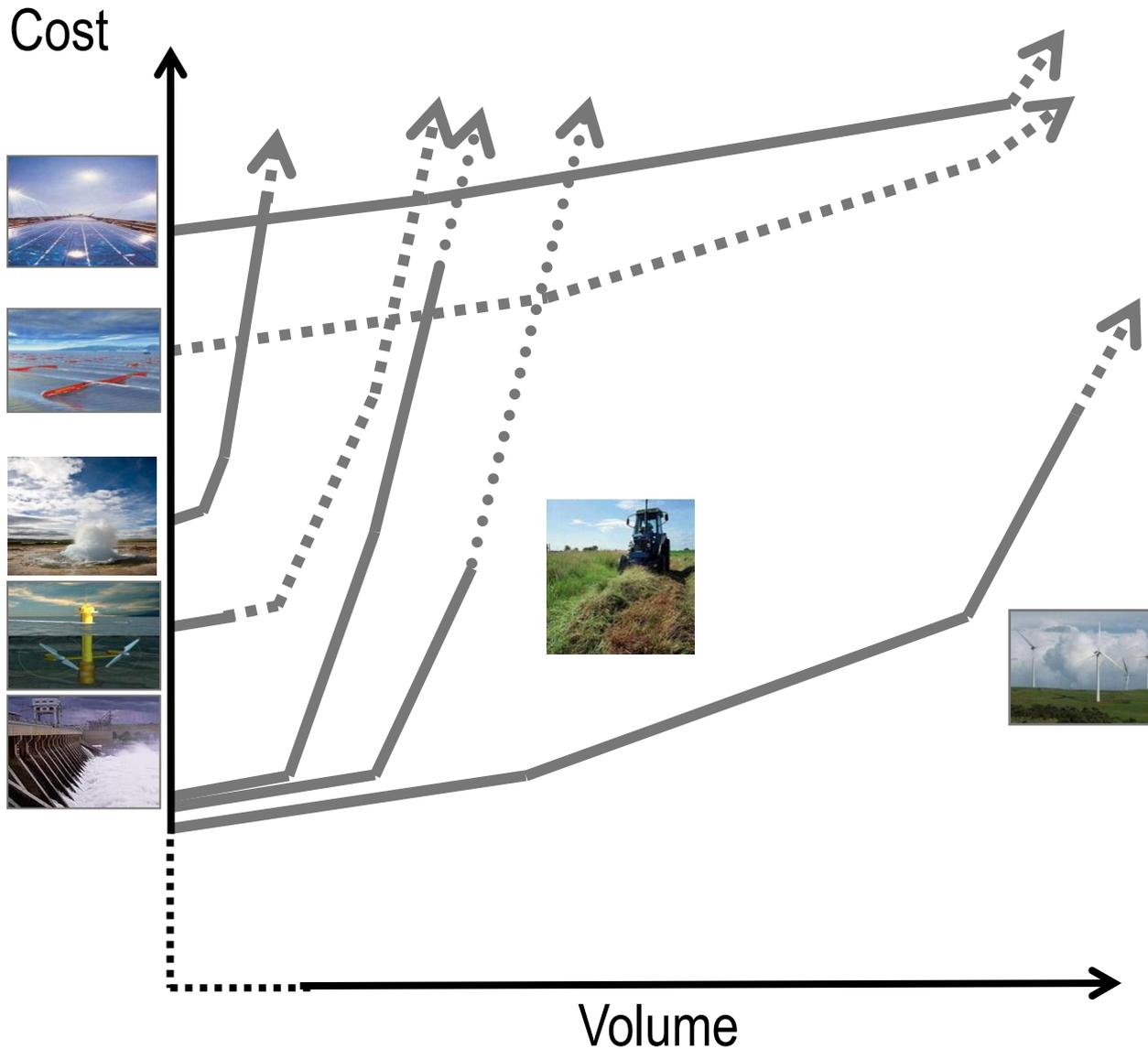
- Renewable resources
- Variable generation characteristics
 - Variable, difficult to predict spatially distributed.
 - Synchronous Electrical Energy Systems
 - Control capability
- Flexibility
 - Metrics
 - Load participation
 - Cycling of thermal plant



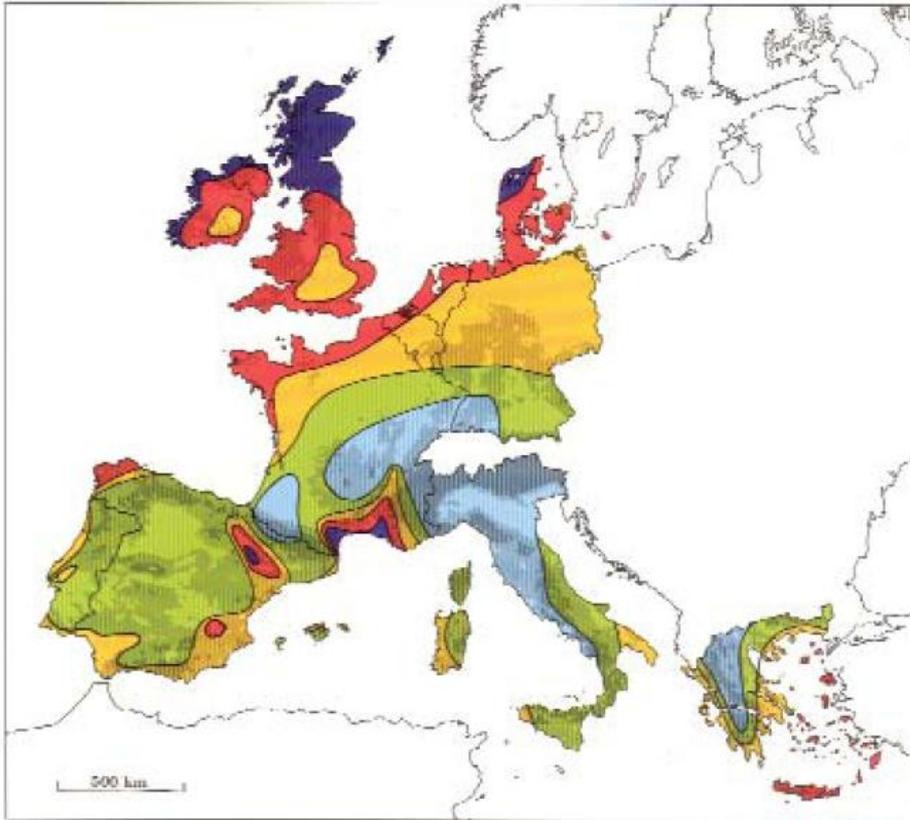


Renewable Resources

Renewable Resources – Ireland

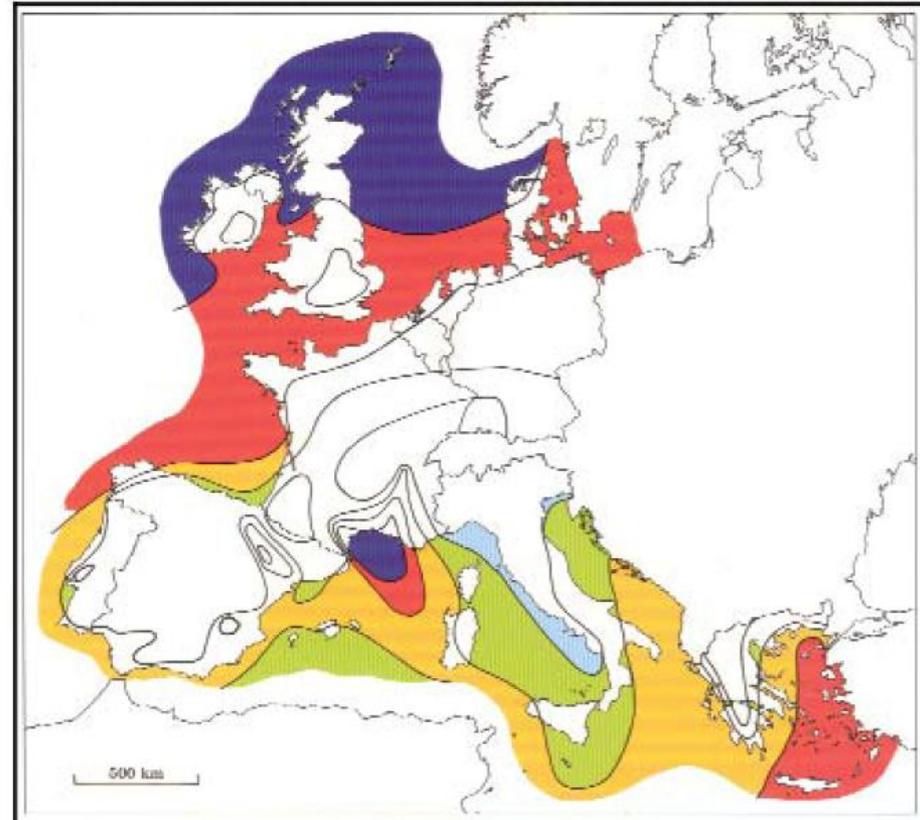


European Wind Resources



Wind resources¹ at 50 metres above ground level for five different topographic conditions

Sheltered terrain ²		Open plain ³		At sea coast ⁴		Open sea ⁵		Hills and ridges ⁶	
ms ⁻¹	Wm ⁻²	ms ⁻¹	Wm ⁻²	ms ⁻¹	Wm ⁻²	ms ⁻¹	Wm ⁻²	ms ⁻¹	Wm ⁻²
> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 600



Wind resources over open sea (more than 10 km offshore) for five standard heights

10 m		25 m		50 m		100 m		200 m	
ms ⁻¹	Wm ⁻²								
> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1600
6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5-8.5	450-650	8.0-9.5	800-900
4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0-7.5	250-450	6.5-8.0	300-600
< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Onshore

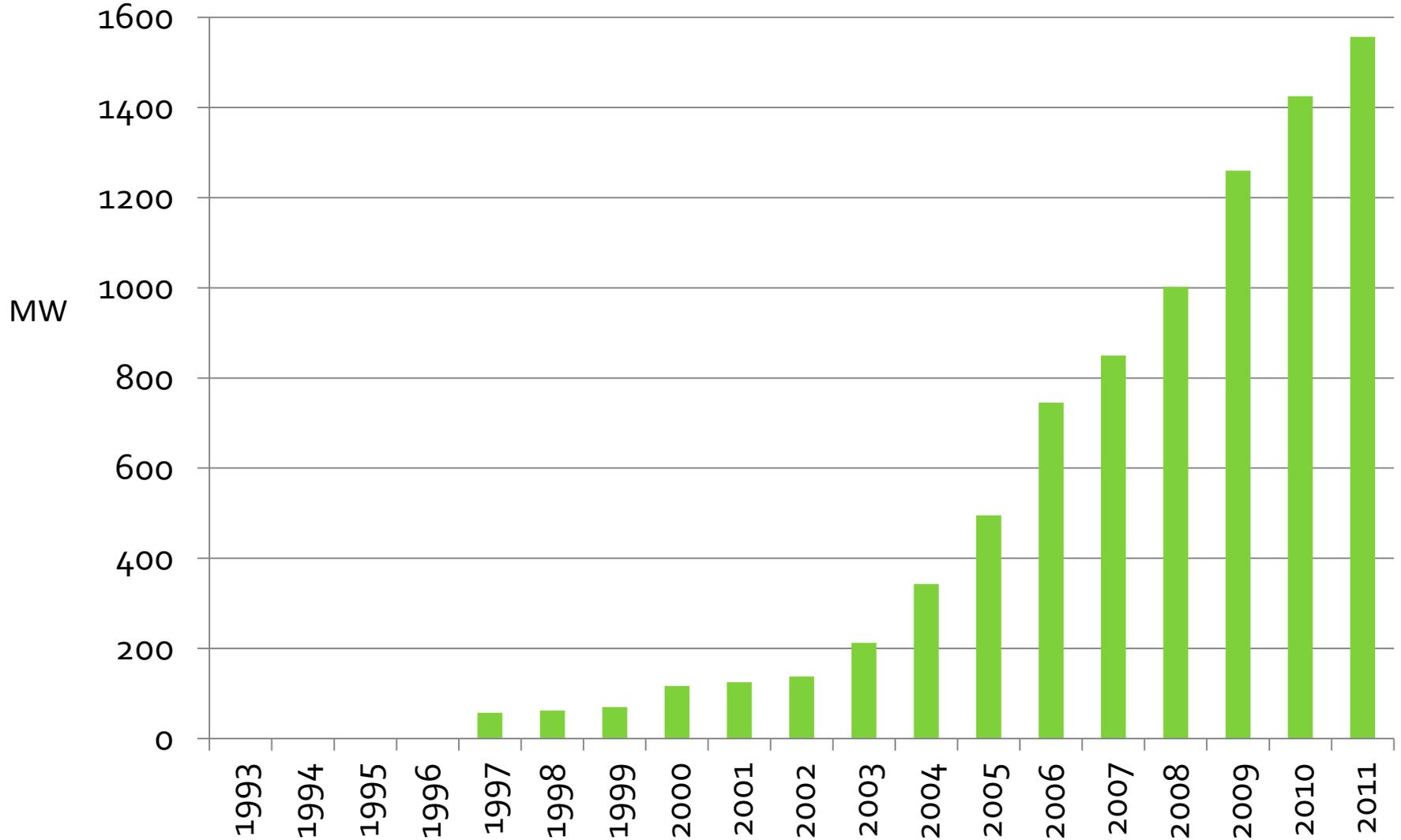
Offshore

Sustainable development commission, Wind Power in the UK, 2005

The Winner: Wind

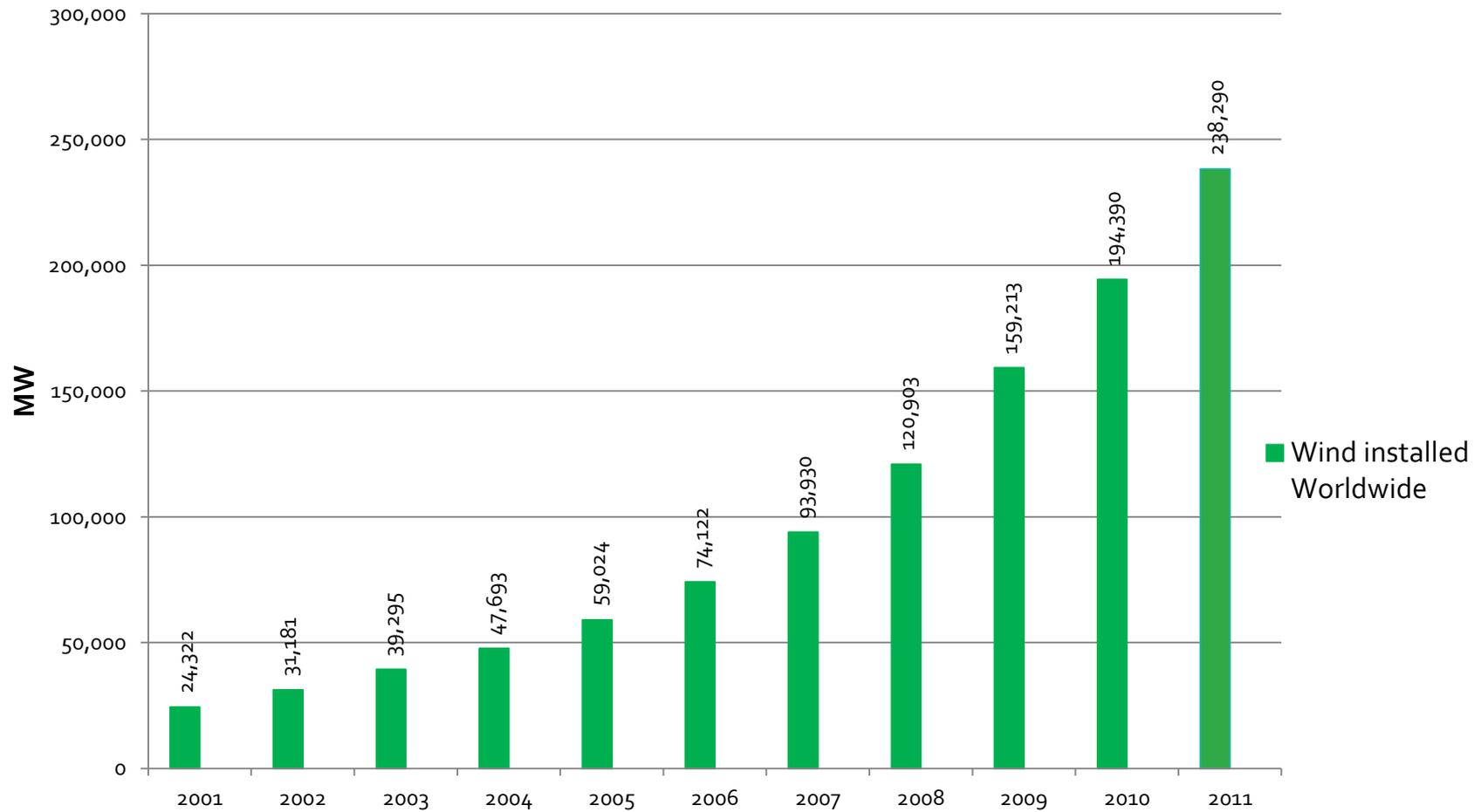


Wind Installed in Republic of Ireland

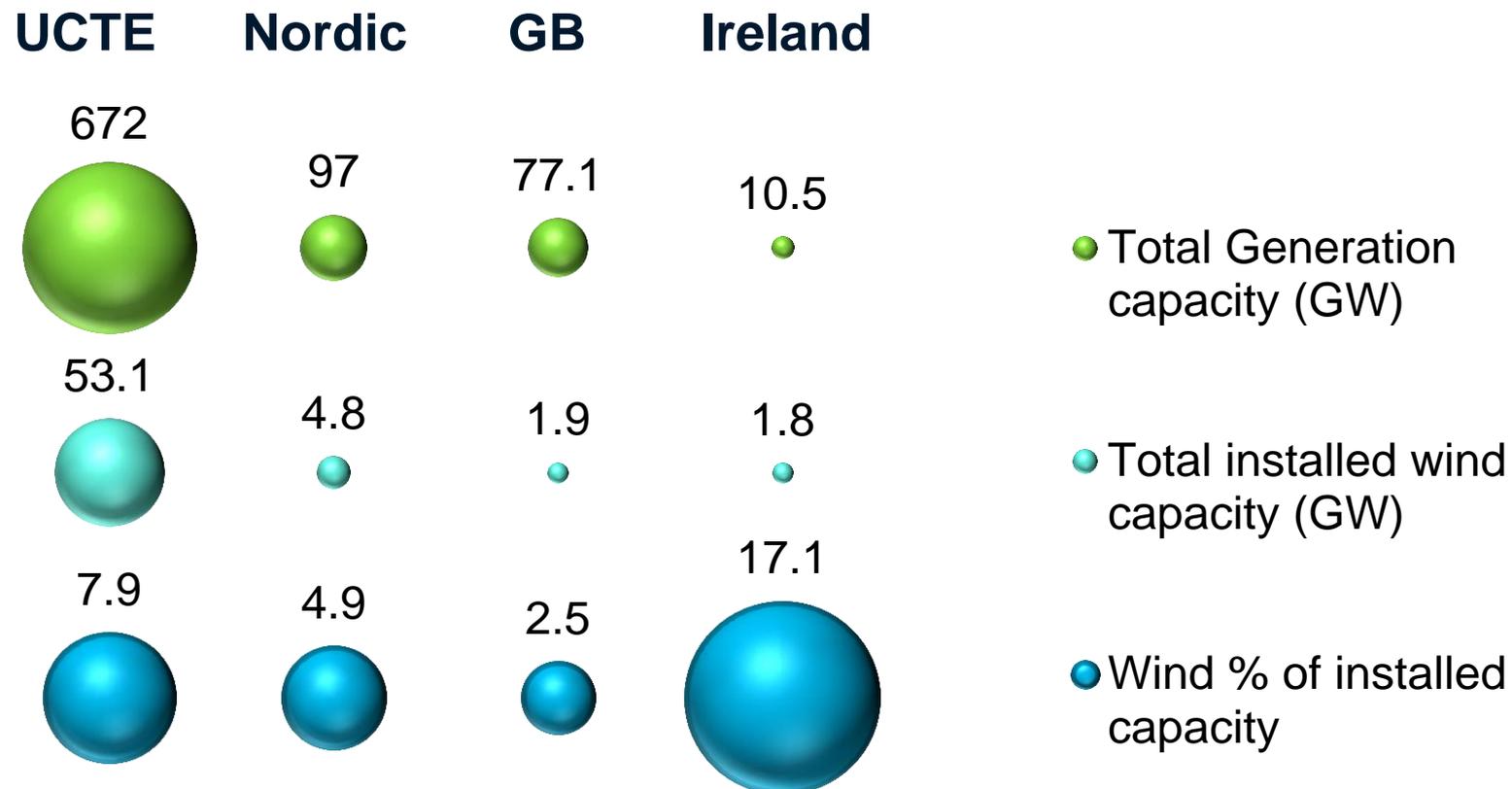


Source: EirGrid

Wind Installed Worldwide



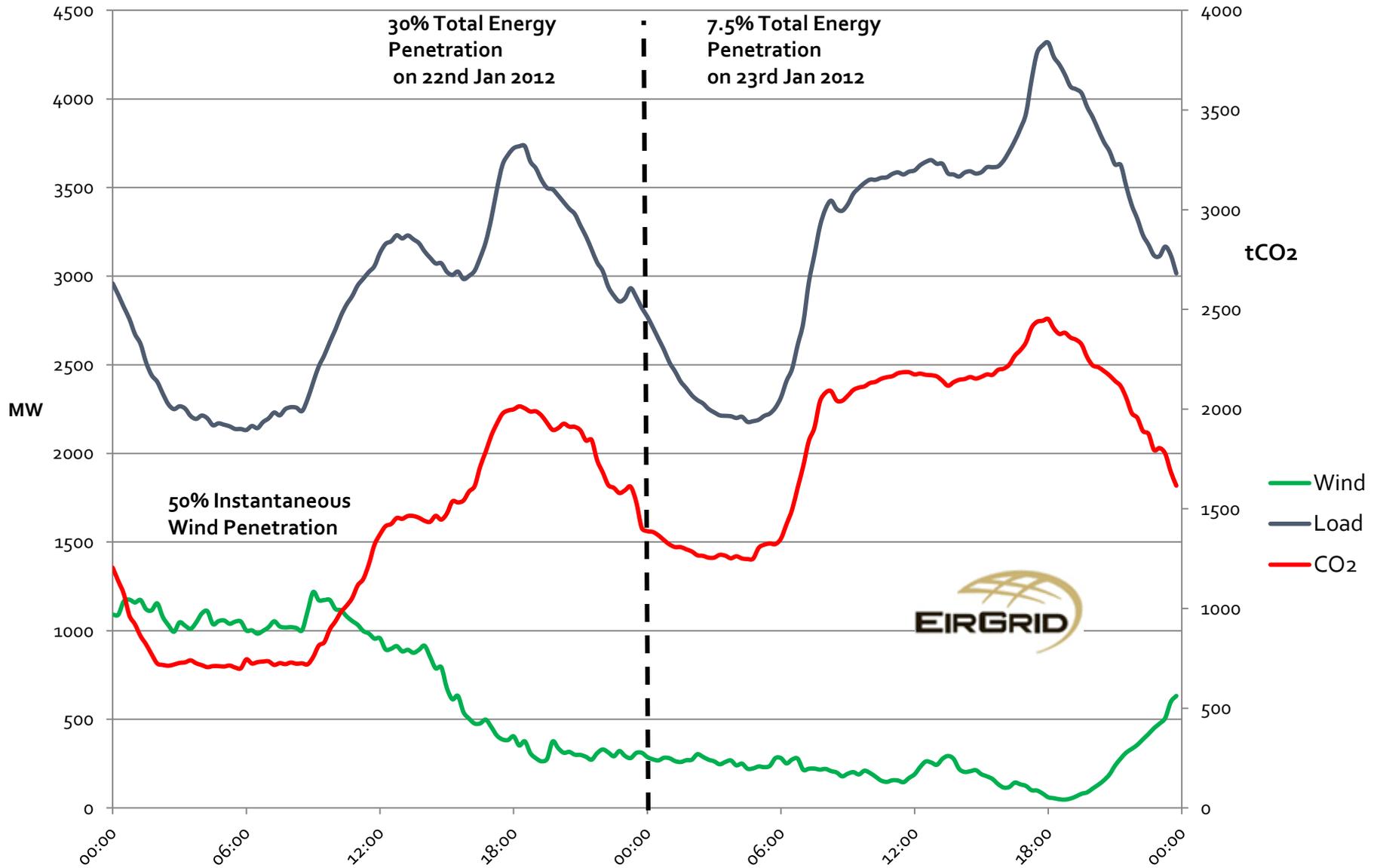
Ireland: Very High Wind Penetration



Figures for end 2008

Source: Global wind energy outlook 2008, EirGrid, UK National Grid, NORDEL, Eurelectric

Load, Wind and CO₂ Republic of Ireland



erc real-time data

electricity research centre

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[graphical records](#)

[realtime home](#)

Download Data:	ROI Demand: Max, Min, Average	ROI Wind: Max, Min, Average	GB Demand: Max, Min, Average	GB Wind: Max, Min, Average
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Notes on Data

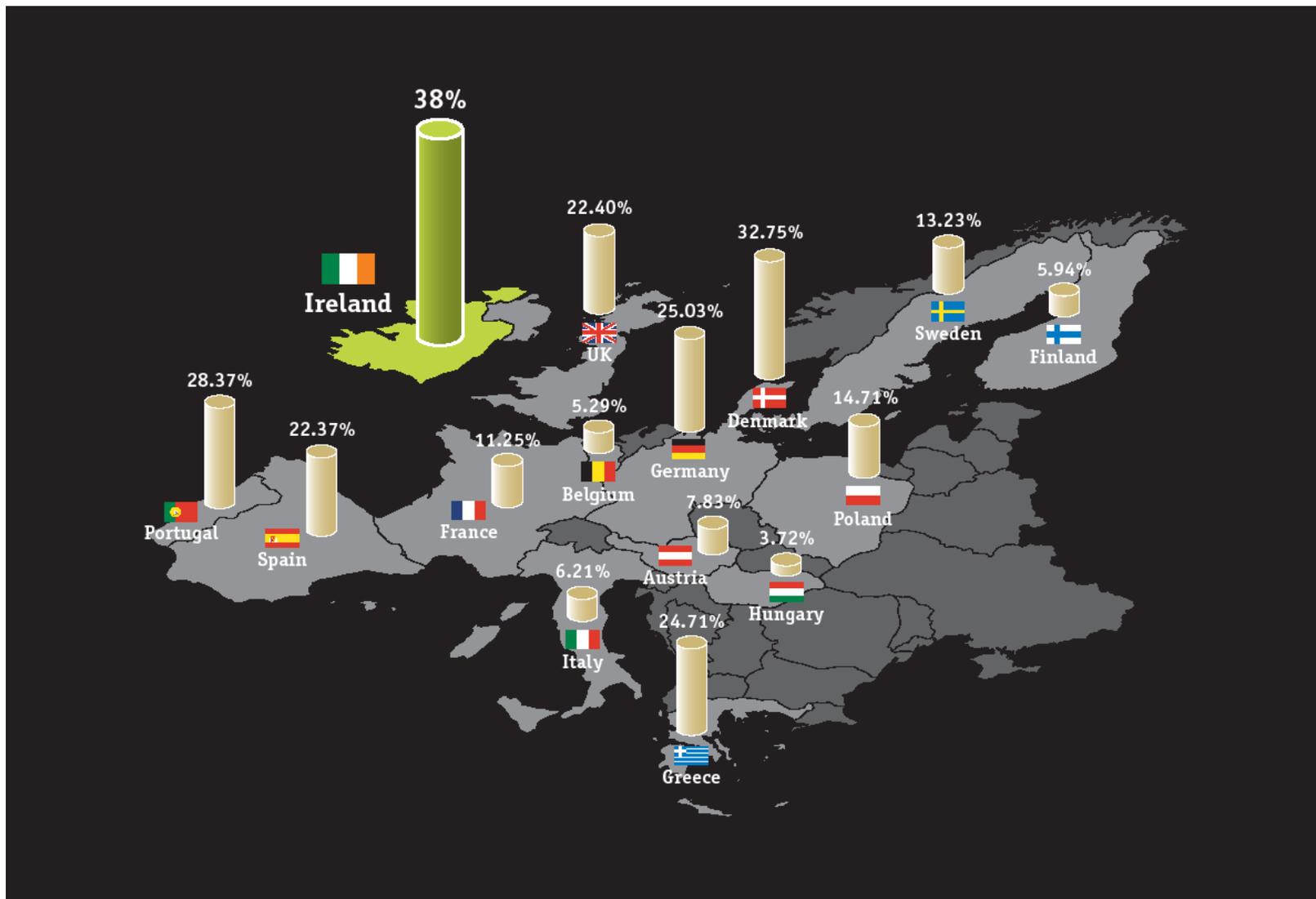
Values quoted represent the recorded maximum and minimum values for wind generation and system demand in the Republic of Ireland and Great Britain for up to a year previous to today.

Times are given in local time.

All values are in MW.

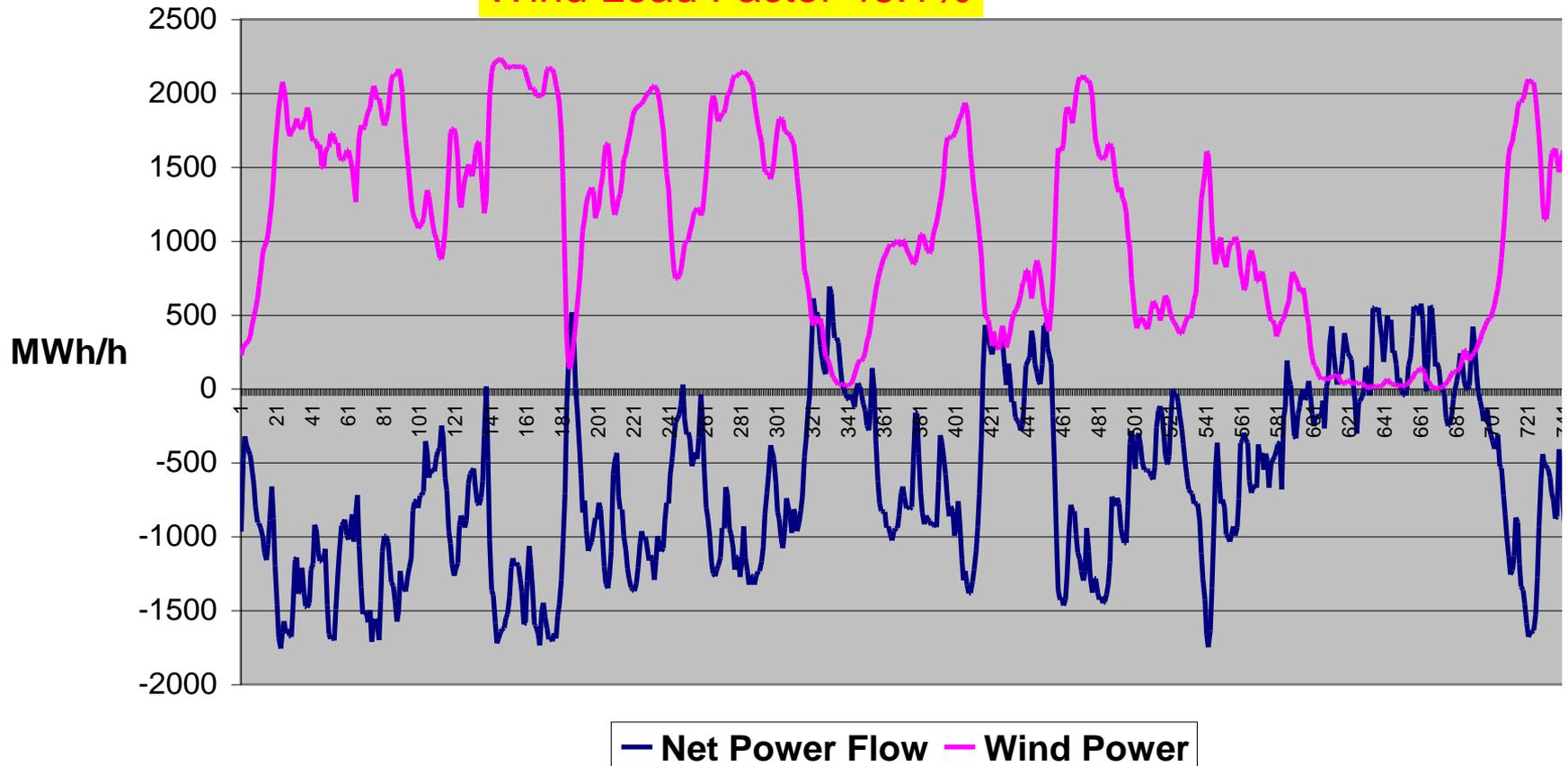
Units: MW	1 Year		3 Months		30 Days	
	Min	Max	Min	Max	Min	Max
Demand Ireland	1,561 <small>08/10/2011 04:15</small>	4,640 <small>13/12/2011 17:30</small>	1,678 <small>04/06/2012 05:45</small>	3,757 <small>25/04/2012 18:00</small>	1,678 <small>04/06/2012 05:45</small>	3,605 <small>07/06/2012 17:45</small>
Wind Ireland	2 <small>06/06/2012 08:30</small>	1,474 <small>26/11/2011 19:30</small>	2 <small>06/06/2012 08:30</small>	1,406 <small>29/04/2012 12:45</small>	2 <small>06/06/2012 08:30</small>	1,260 <small>22/06/2012 16:15</small>

EU Targets 20 20 20



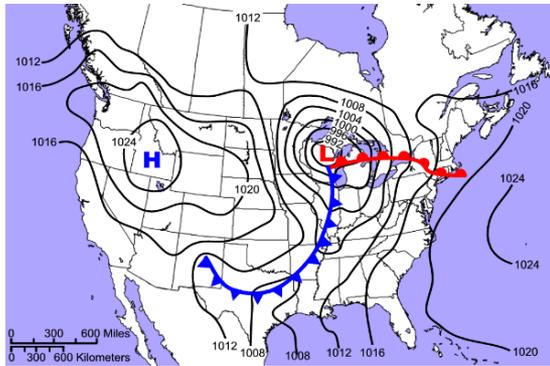
West Denmark Wind Power & Net Power Flow January 2005

Wind Load Factor 46.1%



Penetration Metrics

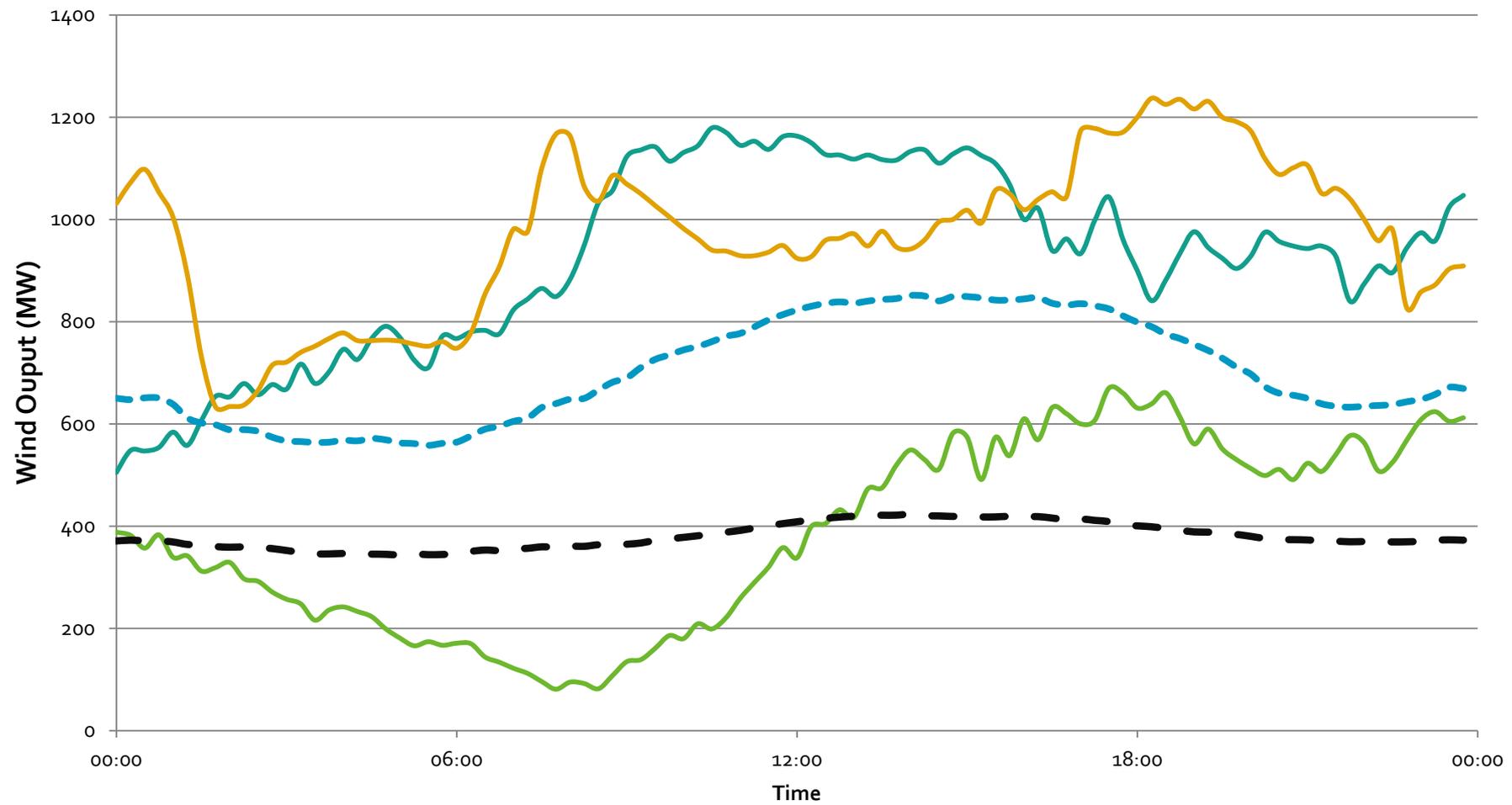
	Capacity pen. (%)	Energy pen. (%)	Max. inst. pen. (no exports) (%)	Max. possible inst. pen. (%)	<i>Söder Metric</i> (%)
Ireland	16.36	10.00	> 50	81.82	67.92
Iberian Peninsula	20.88	15.00	> 55	99.30	93.76
West Denmark	34.95	30.00	>100	195.71	59.05
ERCOT	11.40	8.00	> 25	27.43	26.61
South Australia	22.06	20.00	86	118.63	67.08
Tasmania	5.06	5.00	17 %	18.04	9.96
Crete	16	15.1	> 40	57.14	57.14



Variable, difficult to predict and spatially distributed

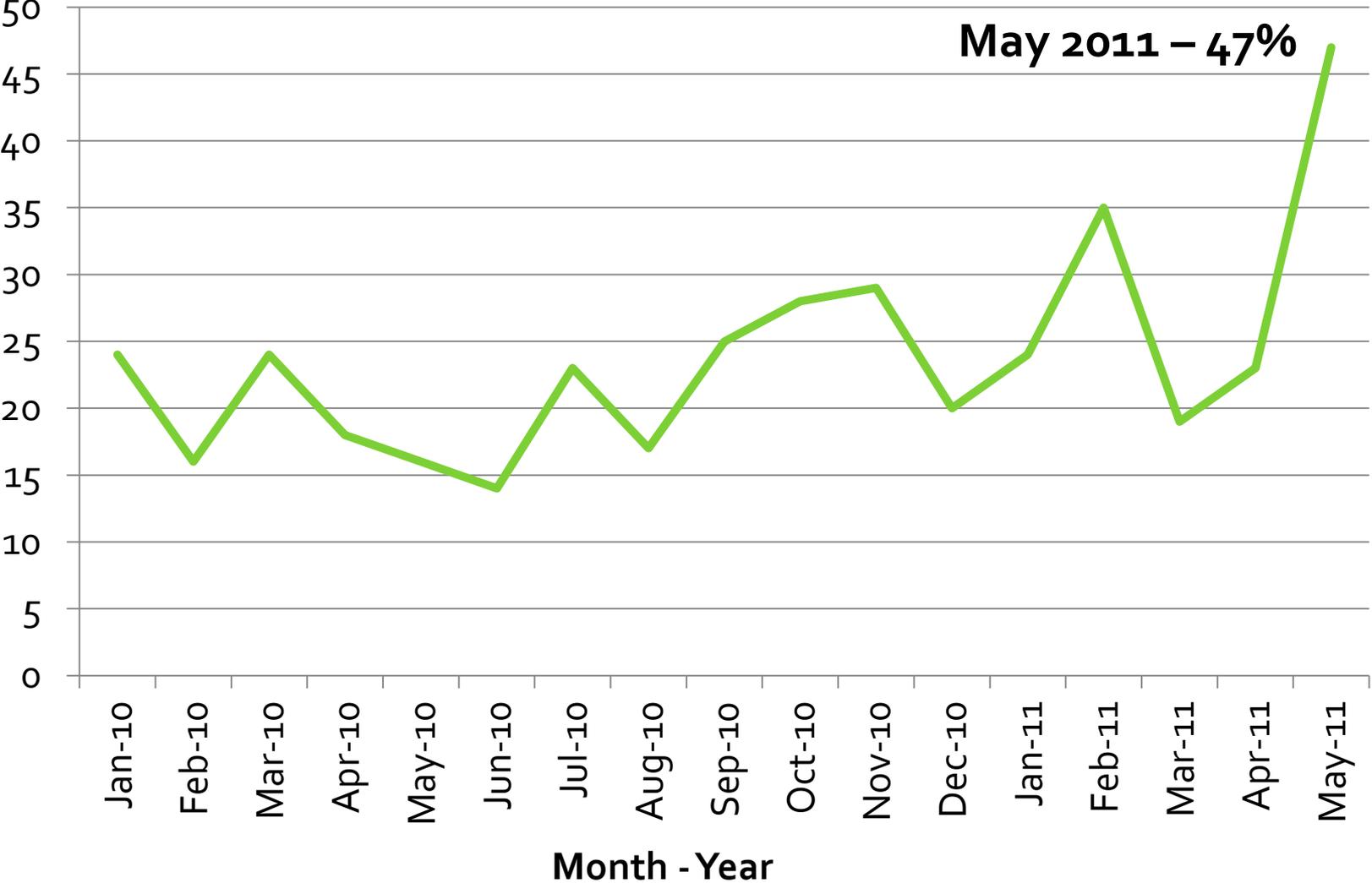
Wind generation variability

May 2011 Wind Output

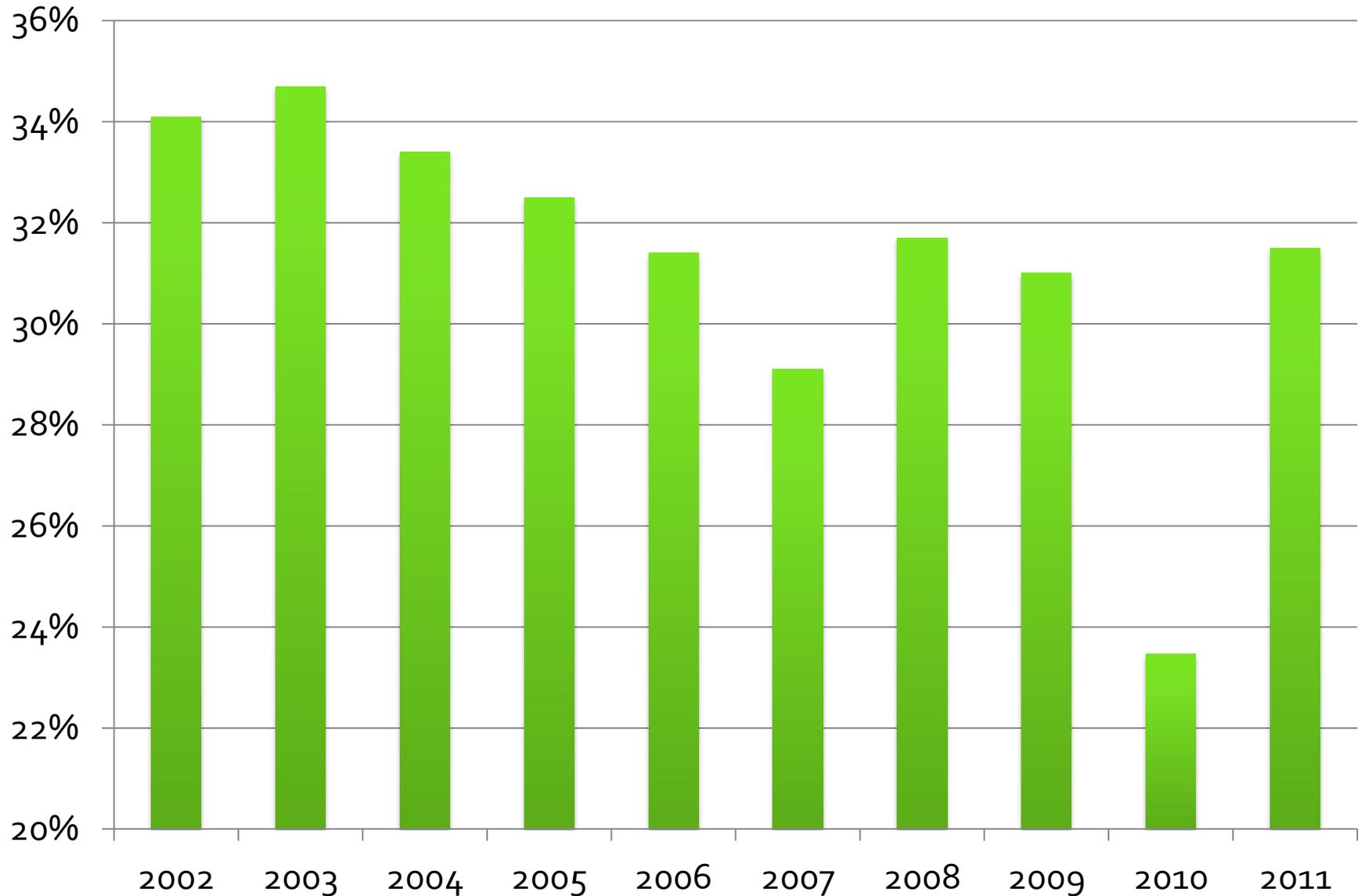


— 19th May — 21st May — 23rd May - - - May Average - - - Yearly Average

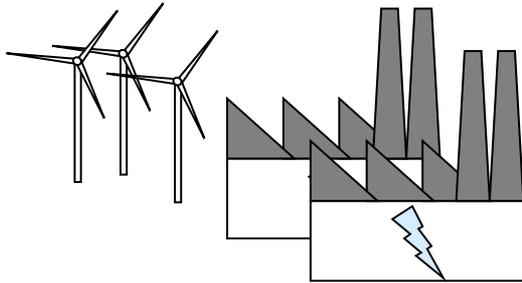
Monthly Capacity Factor – Ireland



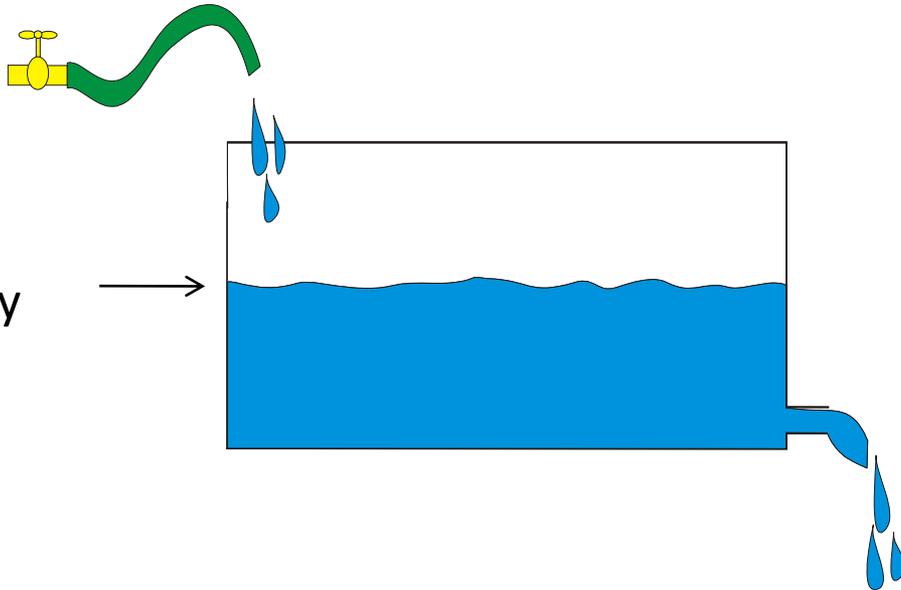
Capacity factor (Republic of Ireland)



Supply Demand Balance

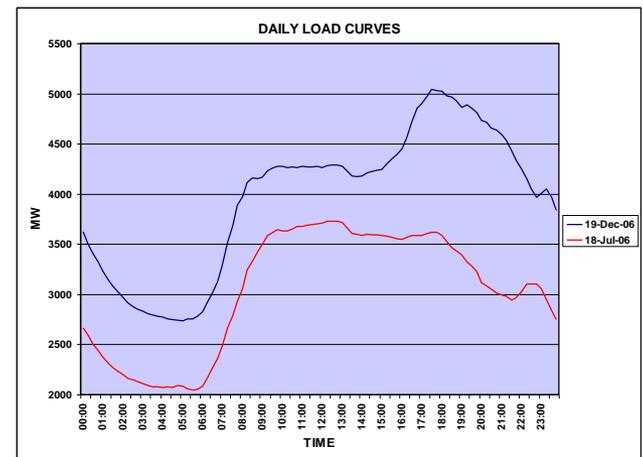


Supply

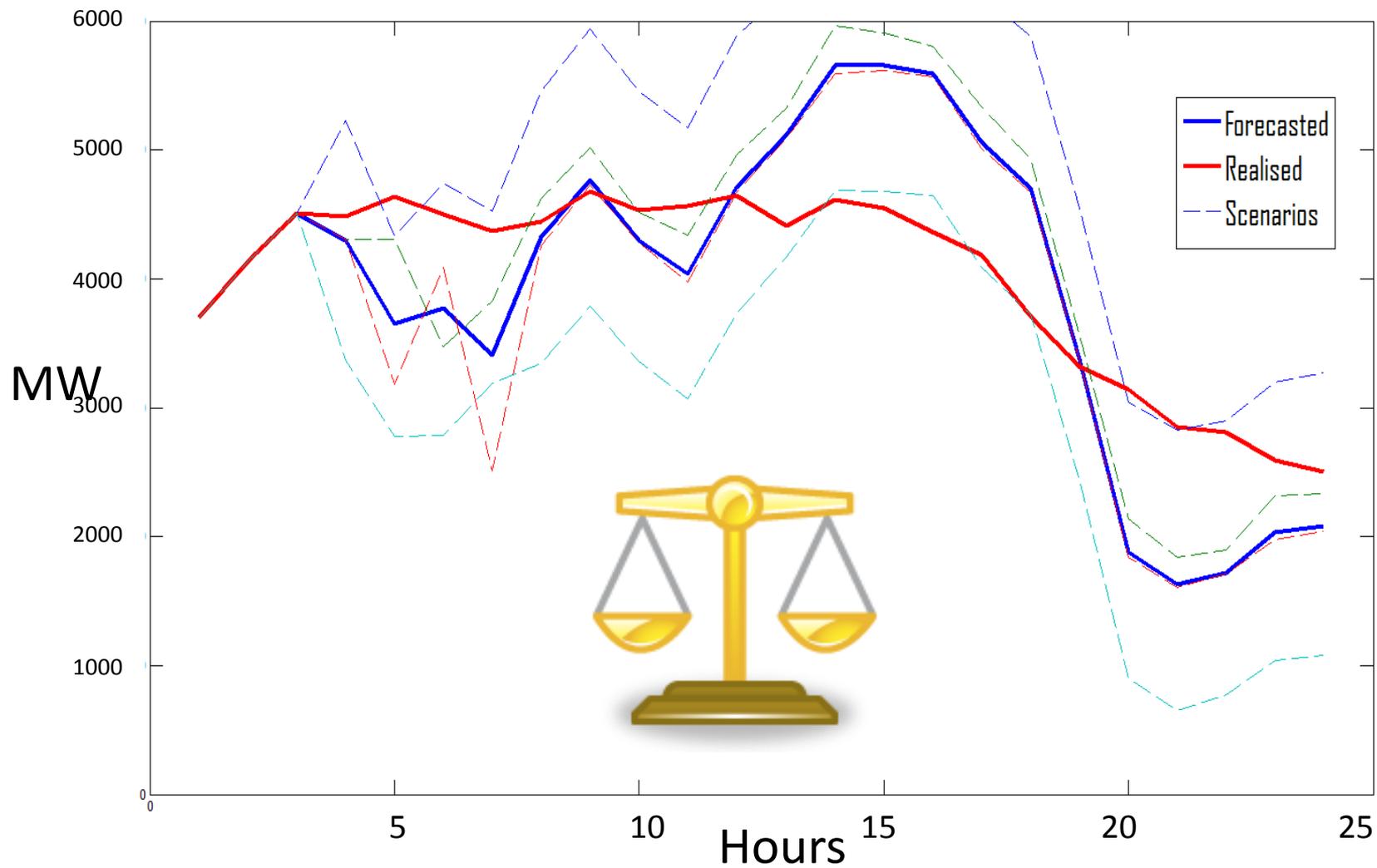


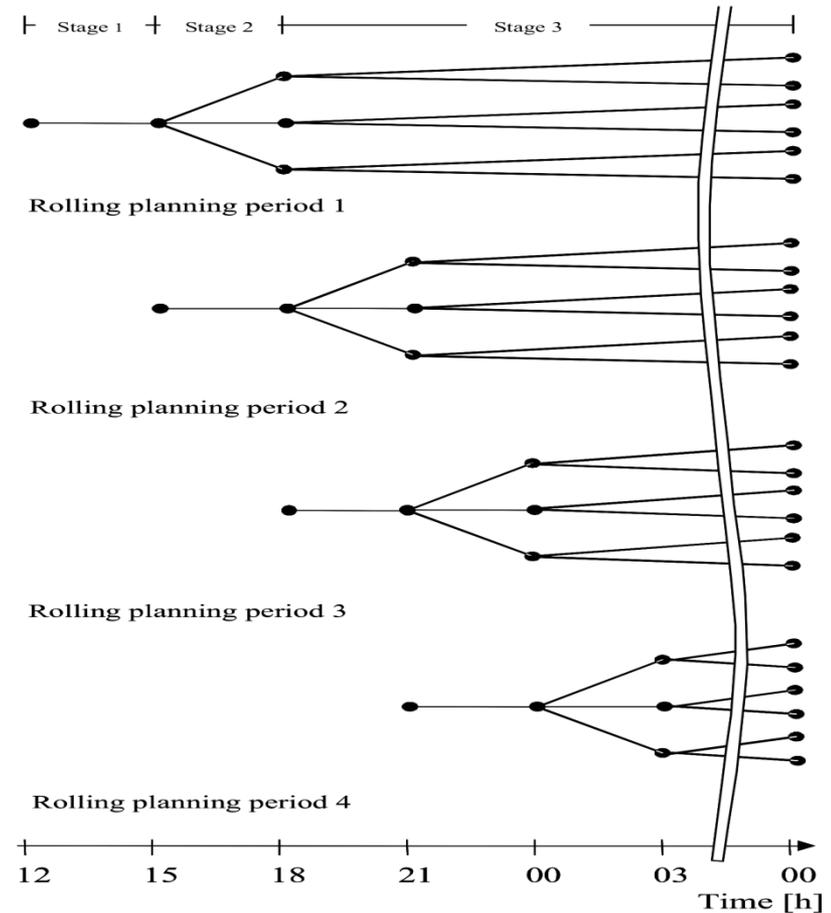
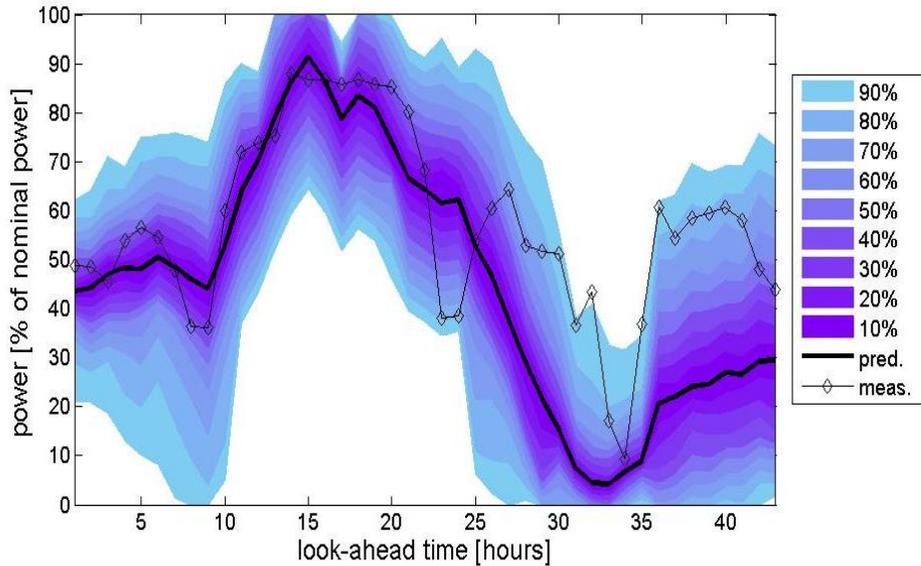
Frequency

Demand



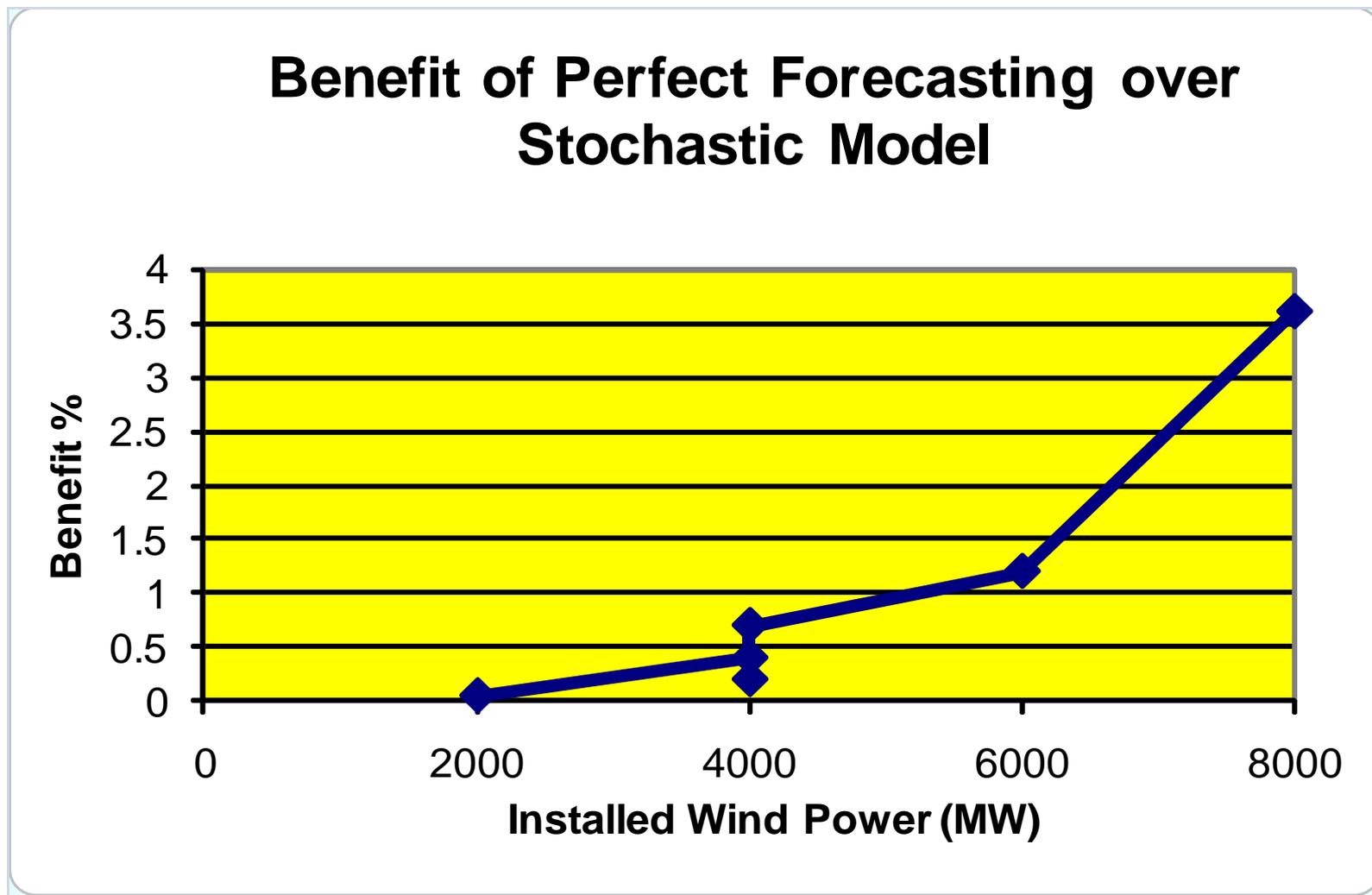
Wind Forecasting





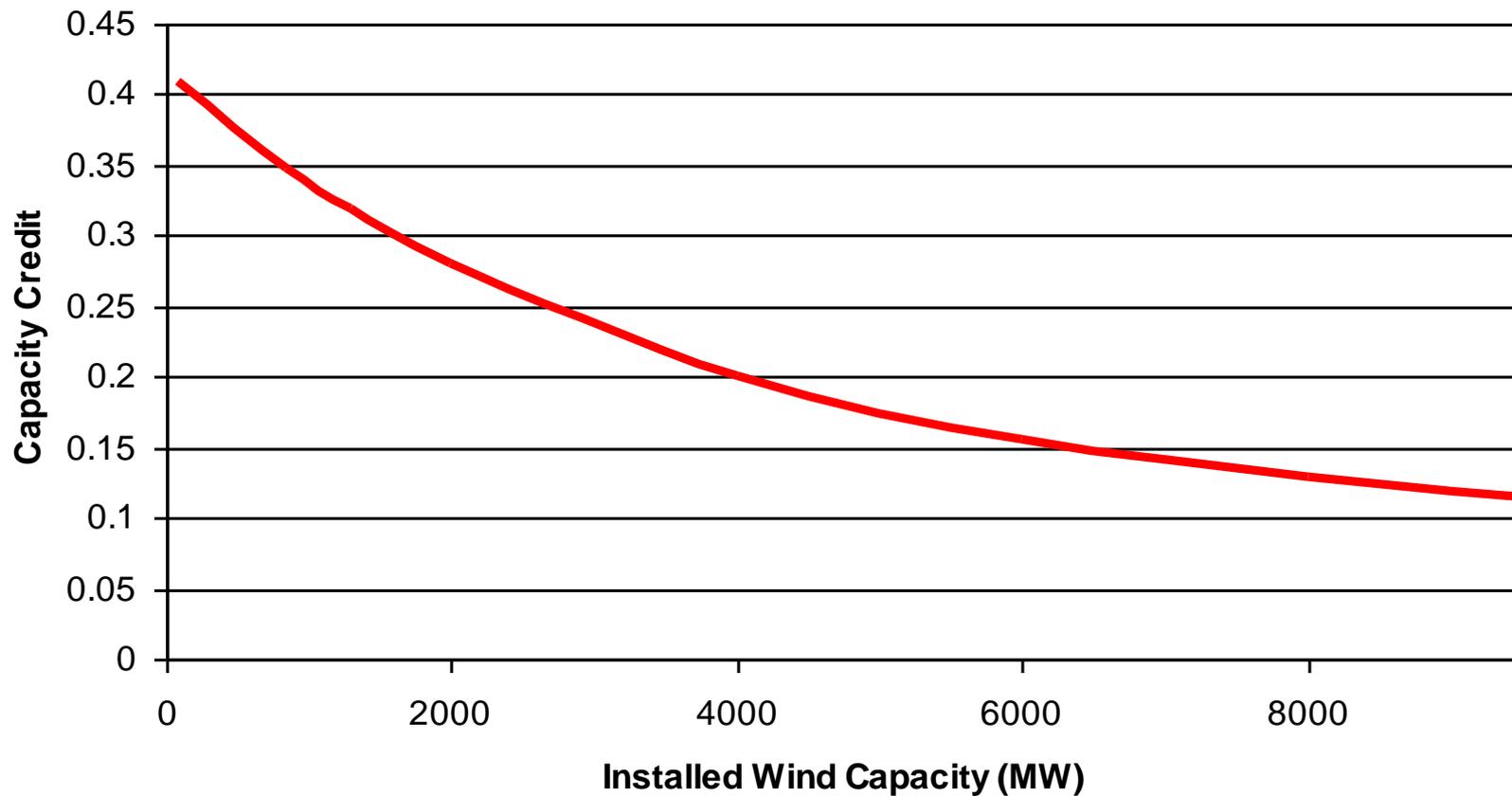
Meibom, P., Barth, R., Hasche, B., Brand, H., Weber, C. and O'Malley, M.J., "Stochastic optimisation model to study the operational impacts of high wind penetrations in Ireland", *IEEE Transactions on Power Systems*, Vol. 26, pp. 1367 - 1379, 2011.

Benefits of Improved Forecasting



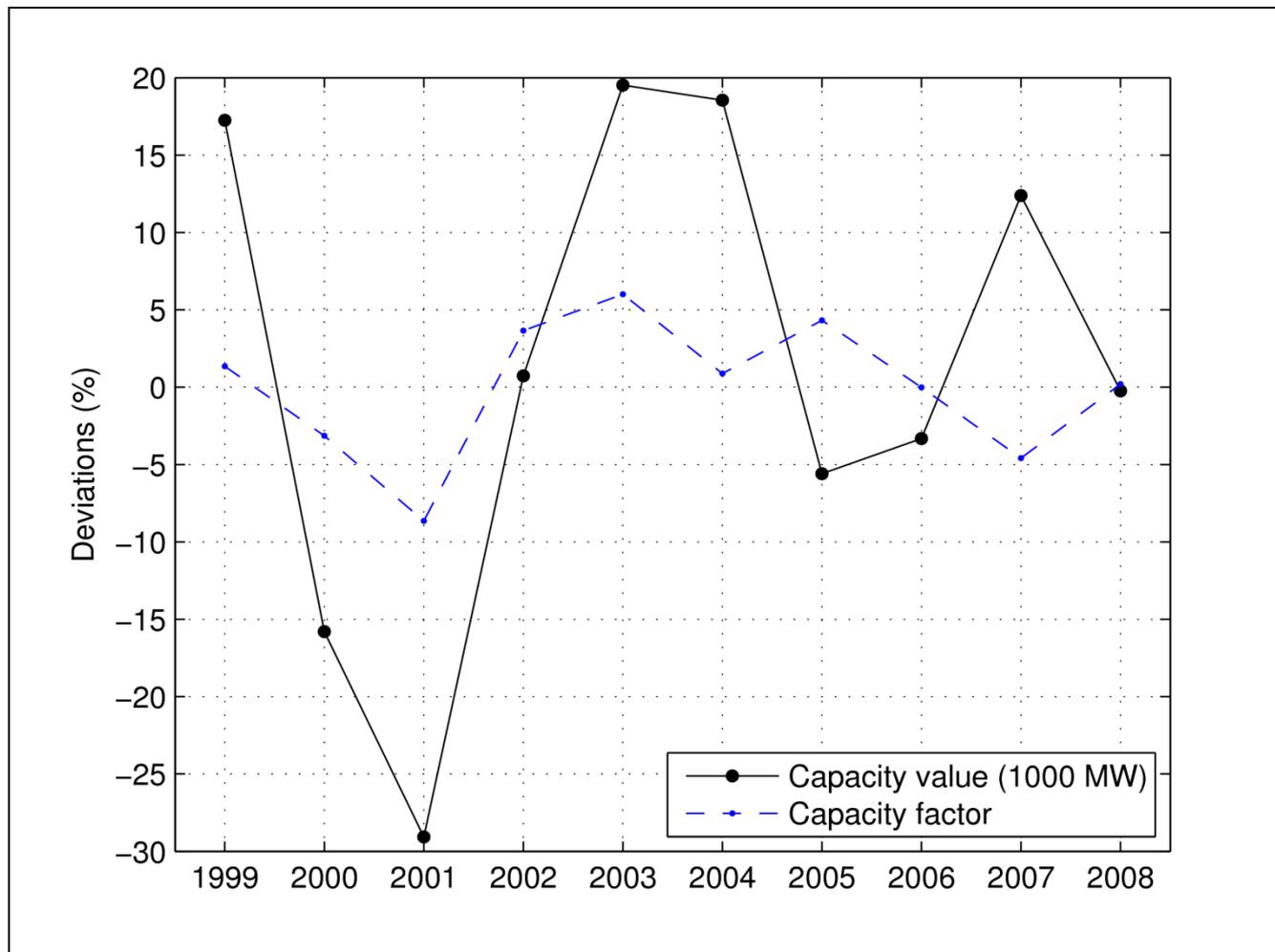
AIGS (2007): All Island Grid Study. Work-stream 2(b): Wind Variability Management Studies
. Department of Communications, Energy and Natural Resources and UK Department of Enterprise, Trade and Investment., Dublin, Ireland.

Wind Capacity Credit



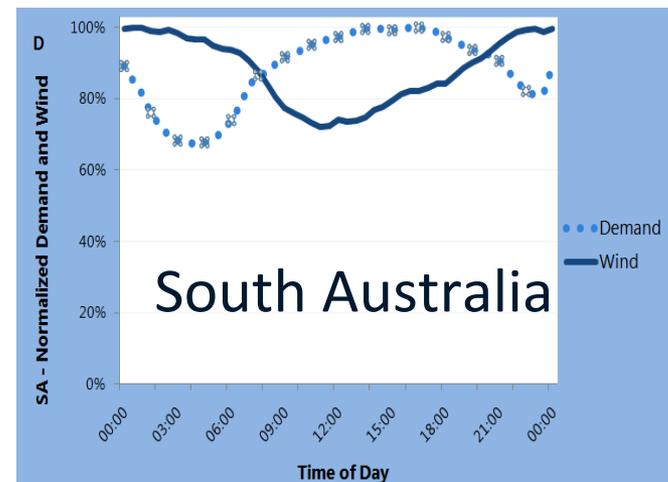
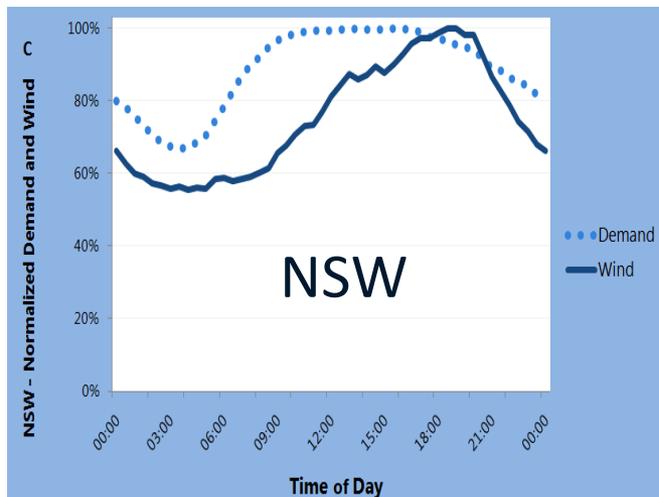
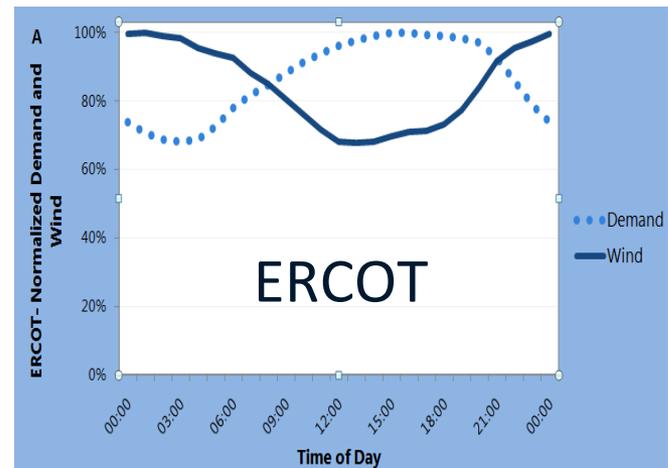
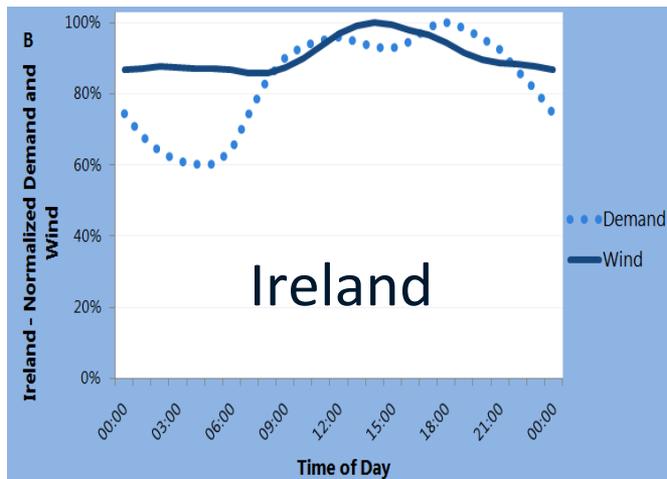
•Keane, A., Milligan, M., D'Annunzio, C., Dent, C., Dragoon, K., Hasche, B., Holttinen, H., Samaan, N., Soder, L. and O'Malley, M.J., "Capacity Value of Wind Power, *IEEE Transactions on Power Systems*, Vol. 26, pp. 564 - 572, 2011.

Yearly variations



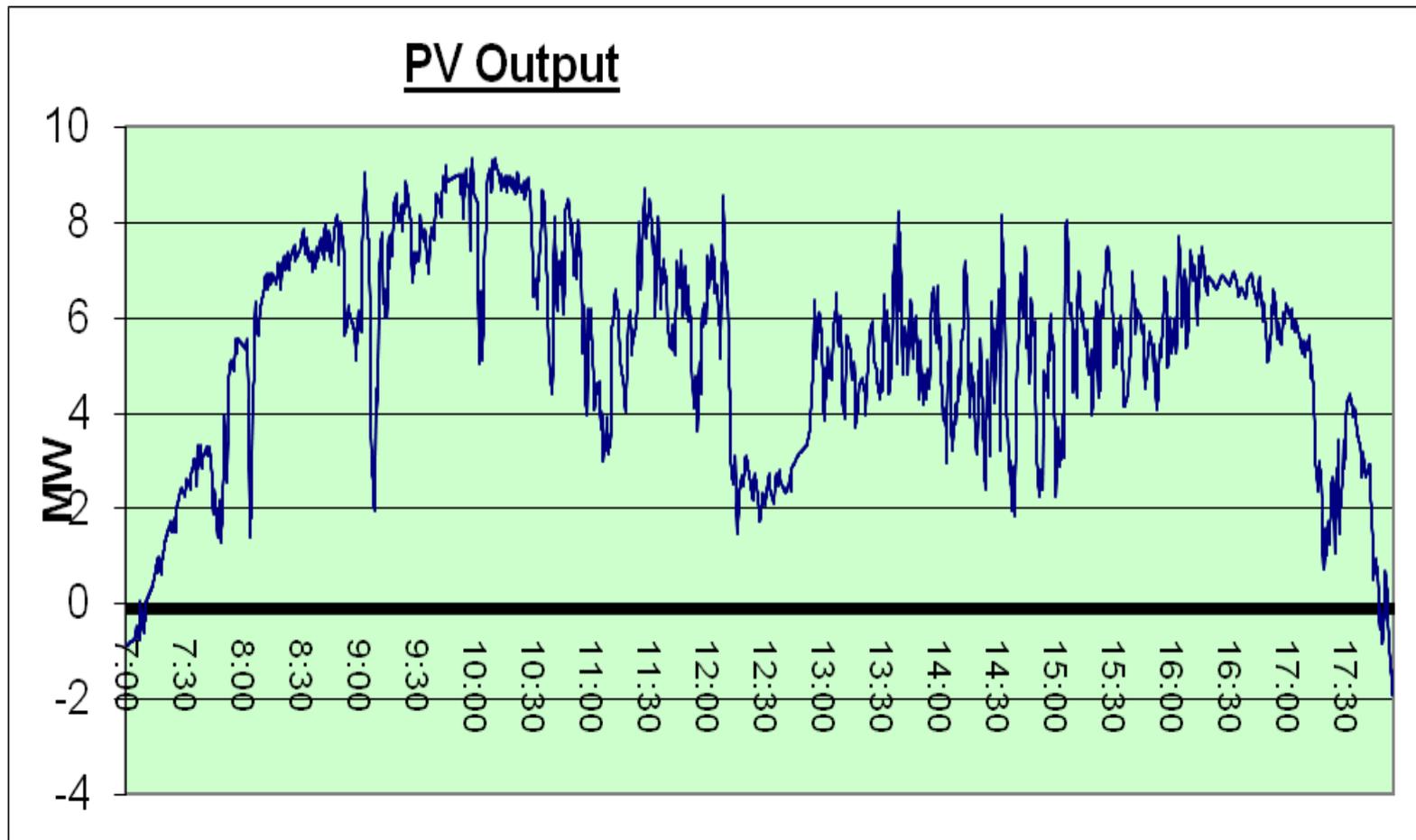
Hasche, B., Keane, A. and O'Malley, M.J. "Capacity credit of wind power: calculation and data requirements", *IEEE Trans. Power Syst.*, Vol. 26, pp. 420 - 430, 2011.

Wind and demand, dance partners ?

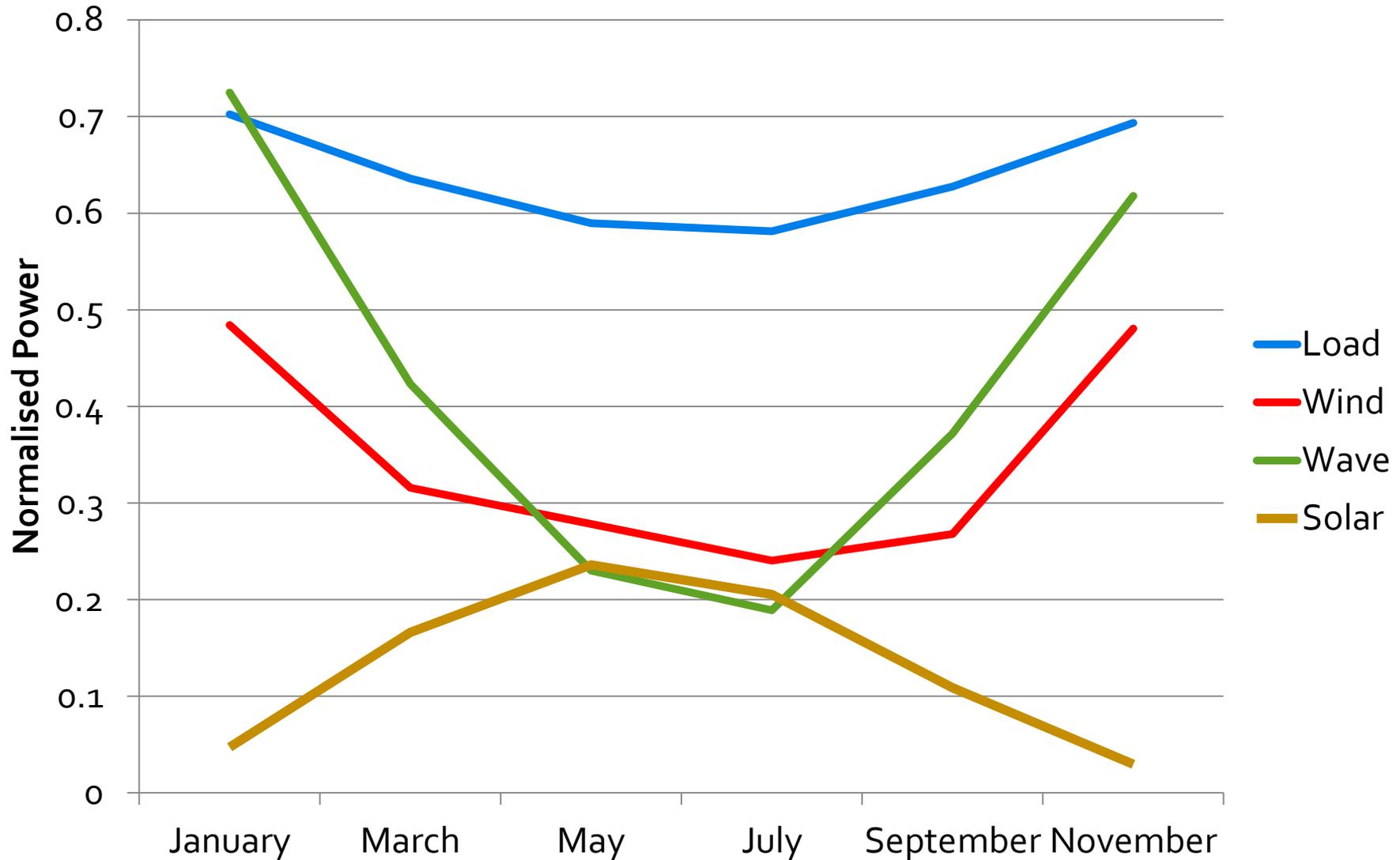


AEMO, Australian Energy Market Operator, “Wind Integration In Electricity Grids: International Practice And Experience” WP1, October 2011

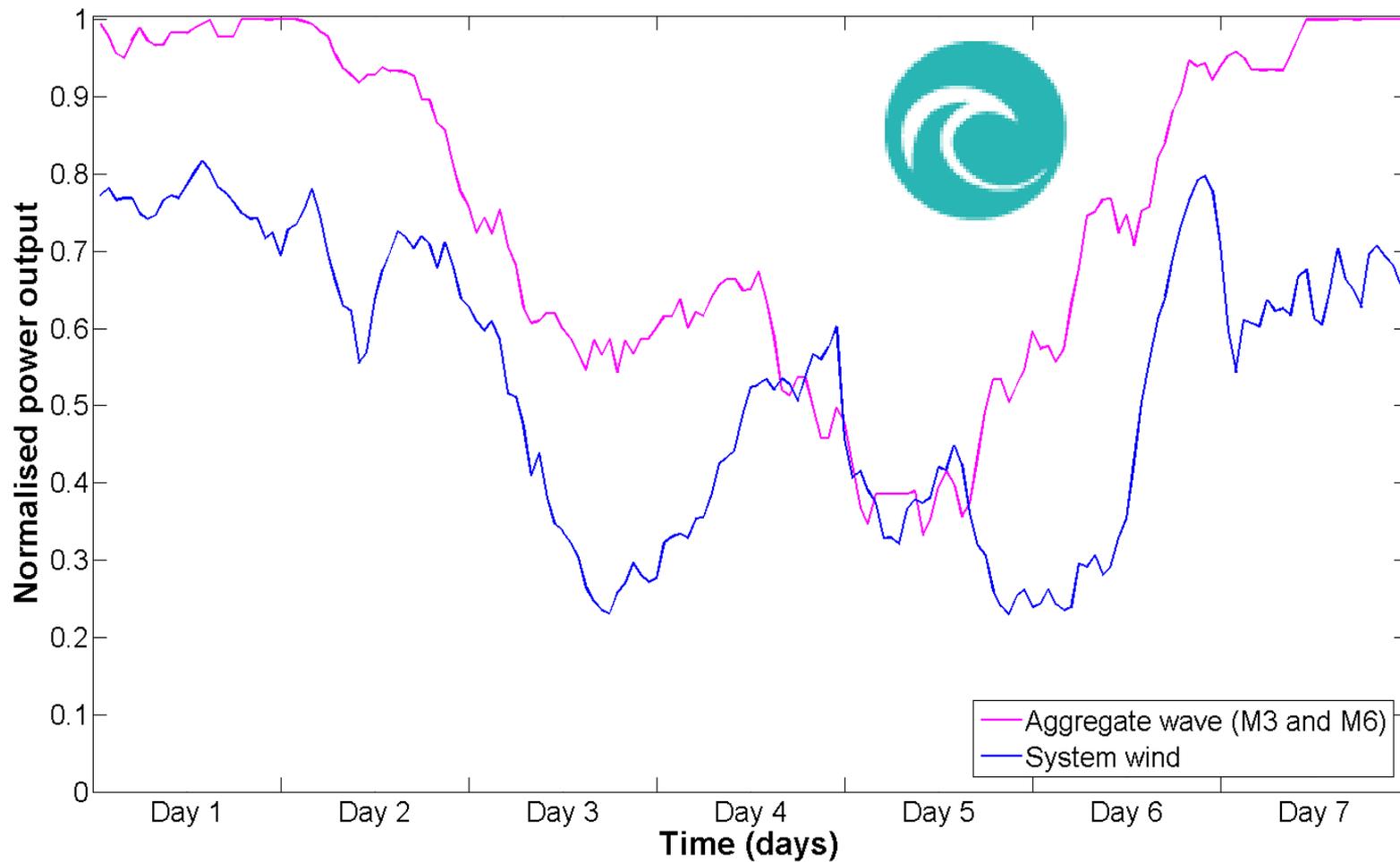
Photovoltaic (PV)



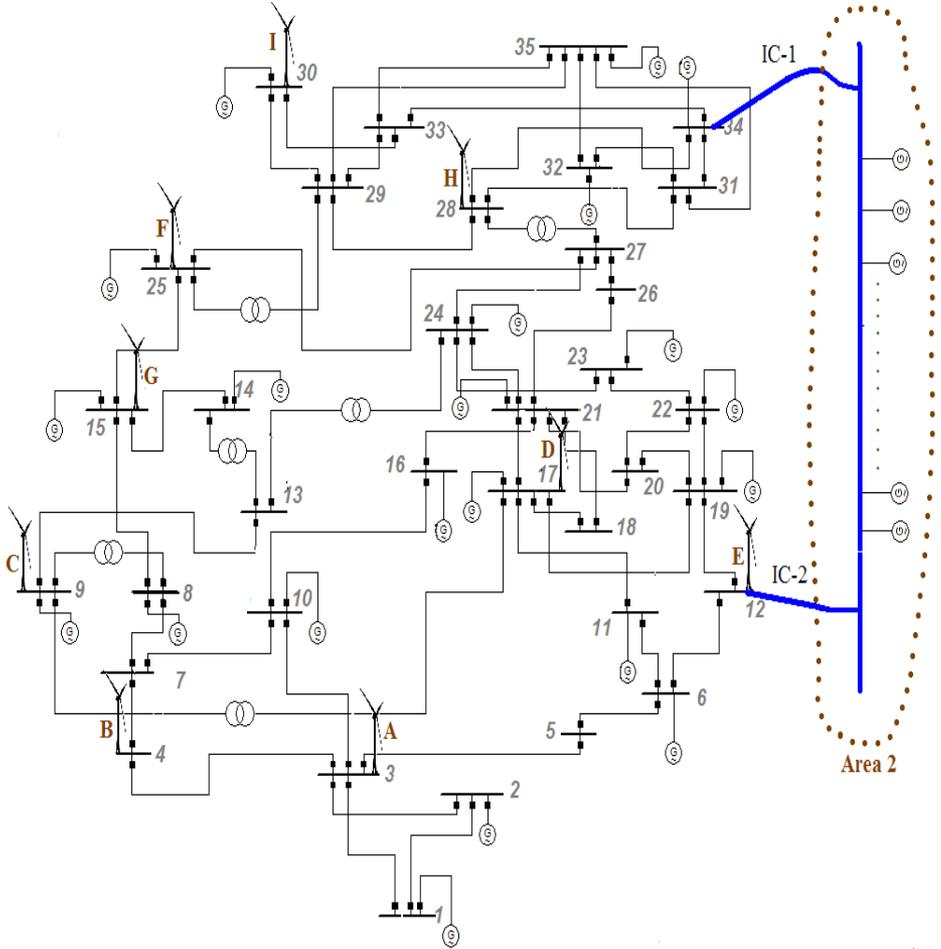
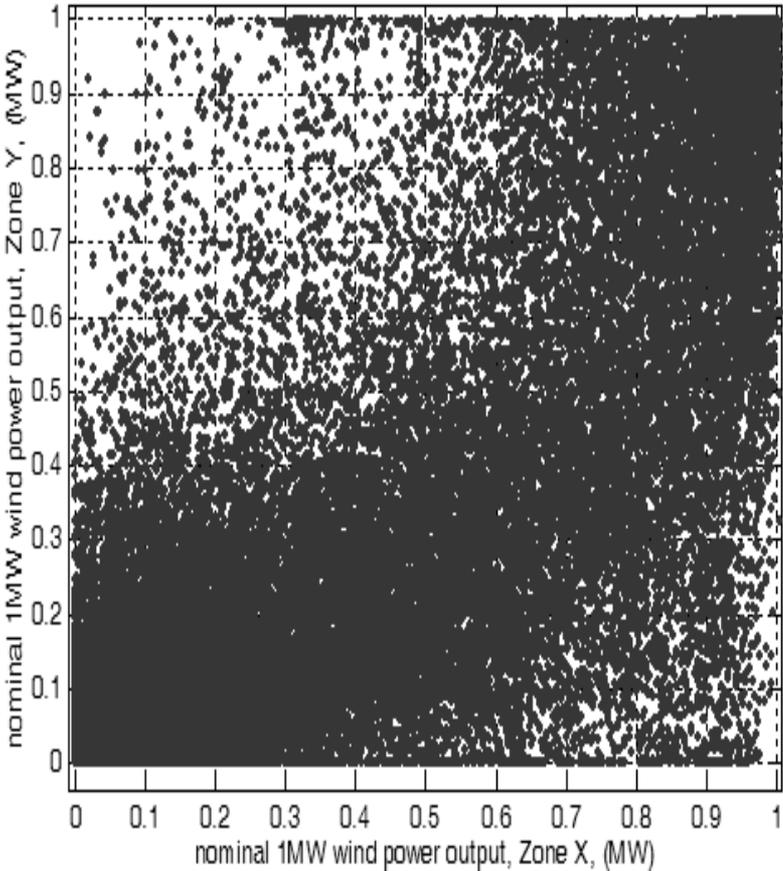
Aggregation of Sources Seasonal - Ireland



Correlation wind and wave energy



Spatially Distributed



Maximising the capacity of the existing grid

Energy % Penetration	Wind Farm Bus Number						
	12	14	15	25	27	29	30
5	0	0	93.1	0	81.4	0	0
6	0	0	101.3	0	90.2	0	0
7	0	0	88.1	9.5	147.0	0	0
8	33.4	38.9	45.0	35.5	138.9	0	0
9	73.6	51.6	44.6	30.9	128.3	0	0
9.5	68.7	54.6	51.5	40.2	132.7	0	0
10	<i>infeasible</i>						

Burke, D. and O'Malley, M.J., "Maximising firm wind power connection to security constrained transmission networks" *IEEE Transactions on Power Systems*, Vol. 25, pp. 749 – 759, 2010.



Synchronous Electrical Energy Systems

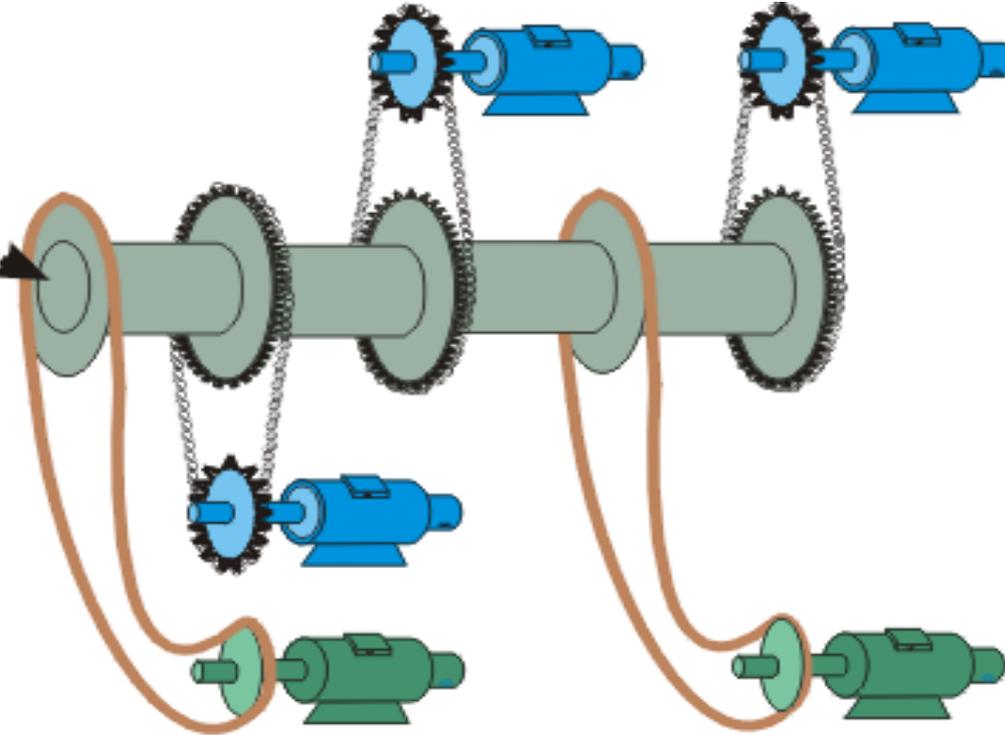
Simple Model of the Grid



50/60 Hz



Synchronous generator



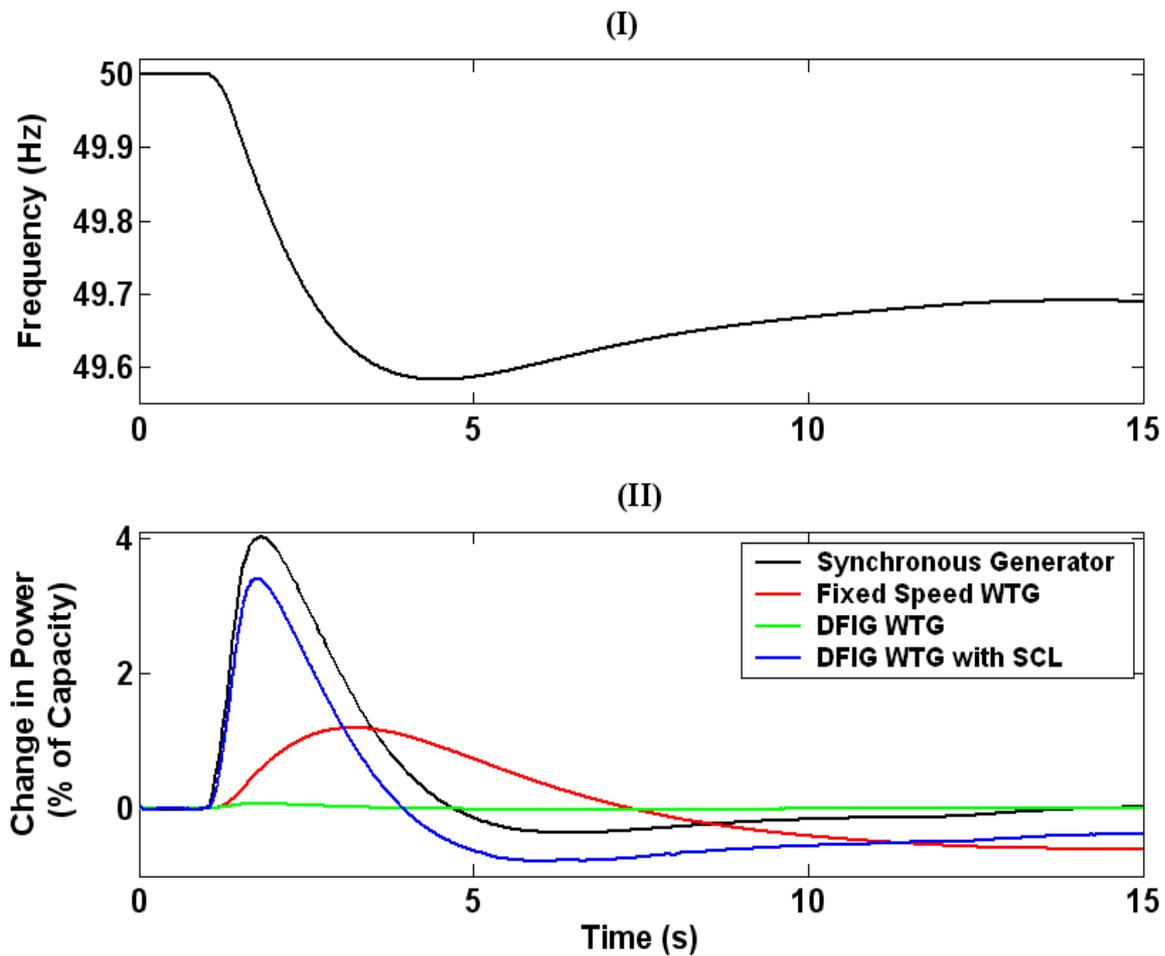
Does not add to system inertia



Doubly fed induction generator wind turbine

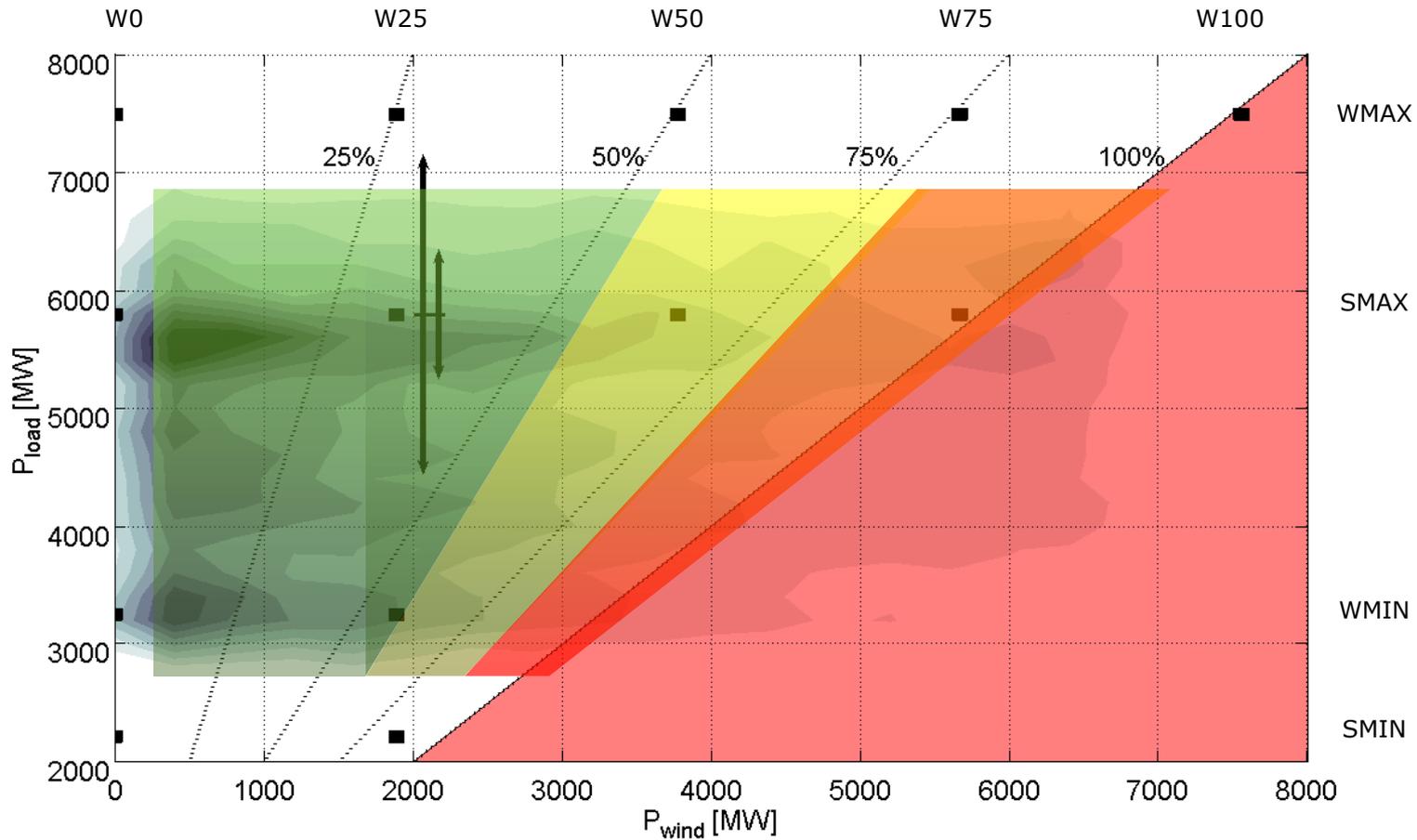
Fixed speed wind turbine generator

Wind Turbine Inertial Response



Mullane, A. and O'Malley, M.J., "The inertial-response of induction-machine based wind-turbines", *IEEE Transactions on Power Systems*, Vol. 20, pp. 1496 – 1503, 2005 .

Operational Boundaries



Frequency response USA



ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

LBNL-4142E

Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation

Joseph H. Eto, Principal Investigator
Lawrence Berkeley National Laboratory

John Undrill
John Undrill, LLC

Peter Mackin, Ron Daschmans, Ben Williams,
Brian Haney, Randall Hunt, Jeff Ellis
Utility Systems Efficiencies, Inc.

Howard Illian
EnergyMark, Inc.

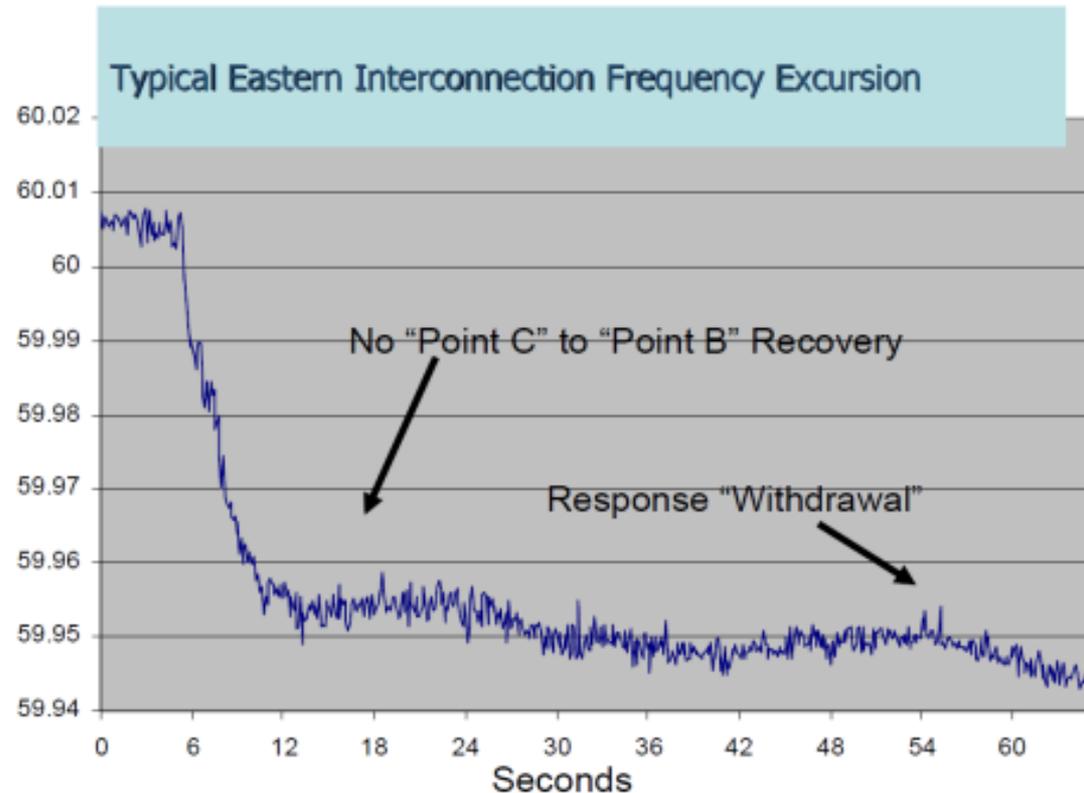
Carlos Martinez
Electric Power Group, LLC

Mark O'Malley
University College Dublin

Katie Coughlin, Kristina Hamachi LaCommare
Lawrence Berkeley National Laboratory

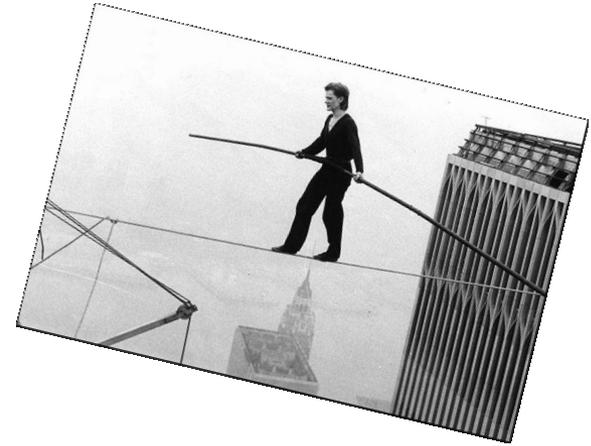
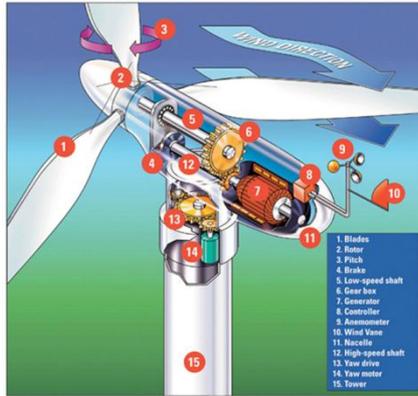
December 2010

The work described in this report was funded by the Federal Energy Regulatory Commission, Office of Electric Reliability. The Lawrence Berkeley National Laboratory is operated by the University of California for the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.



Eto, J., J. Undrill, P. Mackin, R. Daschmans, B. Williams, B. Haney, R. Hunt, J. Ellis, H. Illian, C. Martinez, M. O'Malley, K. Coughlin, and K.H. LaCommare, "Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation", Lawrence Berkeley National Laboratory, Berkeley, 2010.

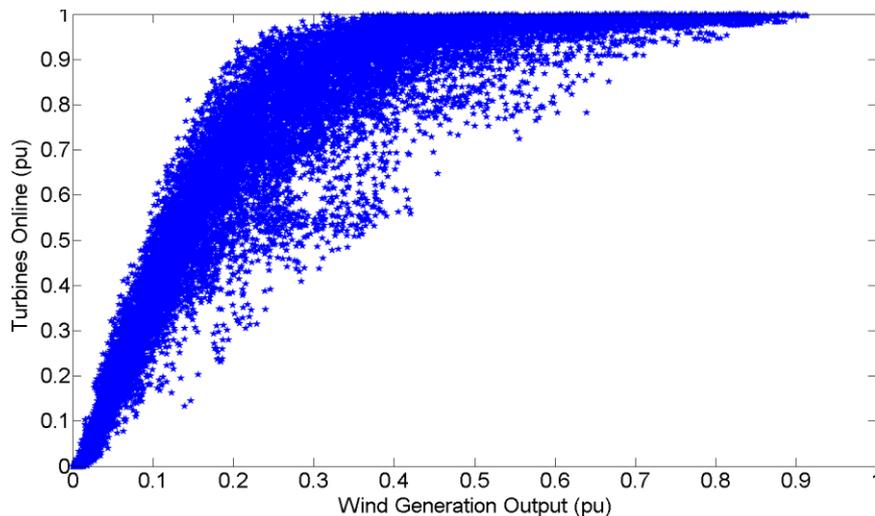
<http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf>



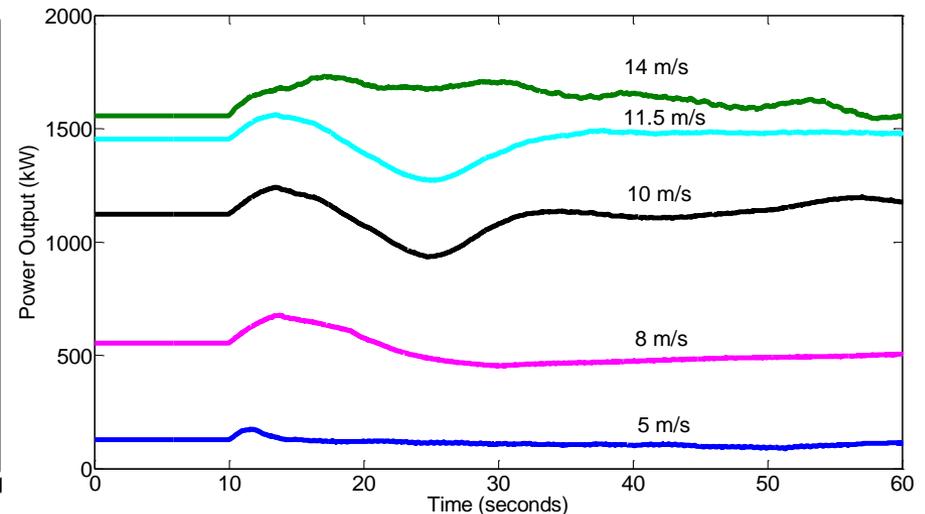
Renewables providing Control

Aggregate Emulated Inertial Response

- Potential response from wind will be stochastic - dependent on:
 - Number of turbines online
 - Operating level of wind turbines



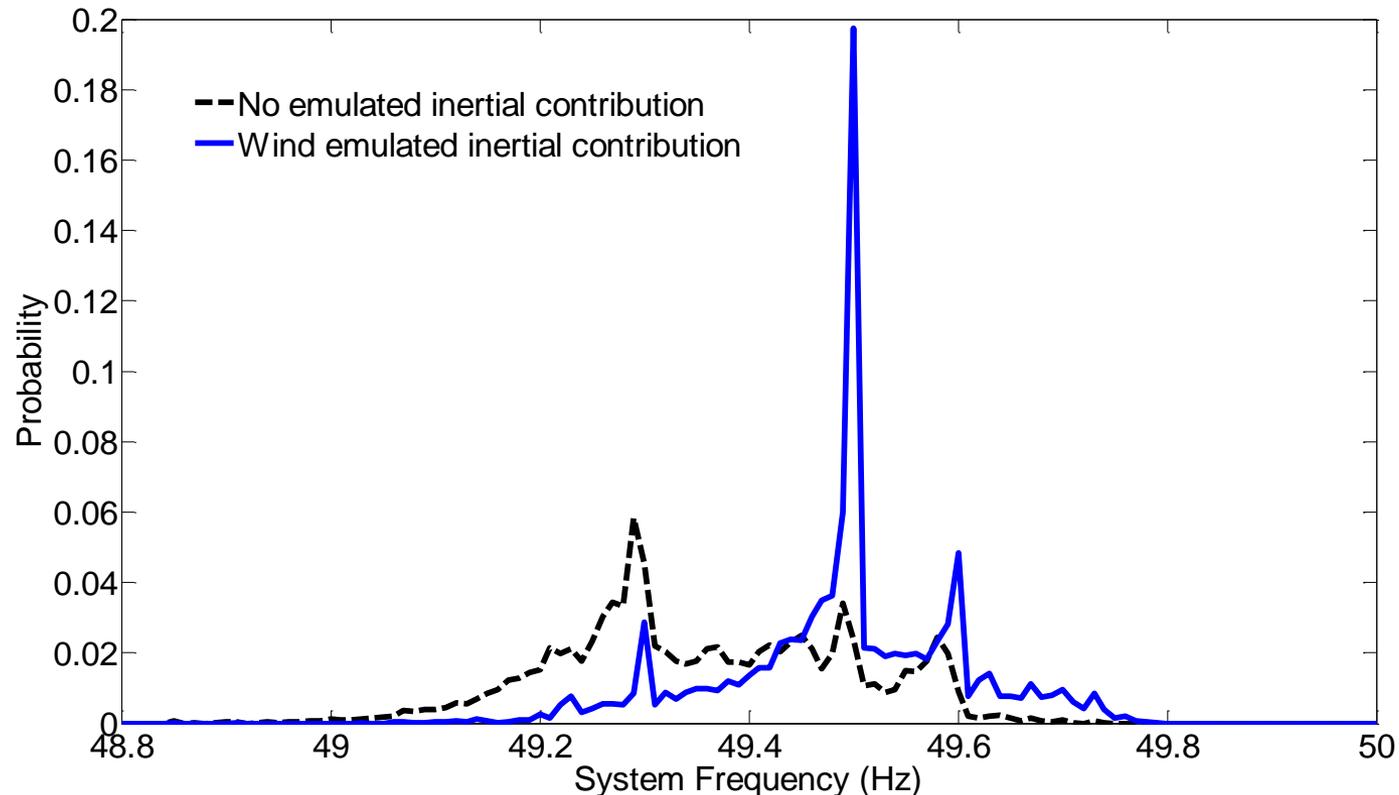
Number of turbines above minimum speed (from wind farm data, across the island of Ireland)



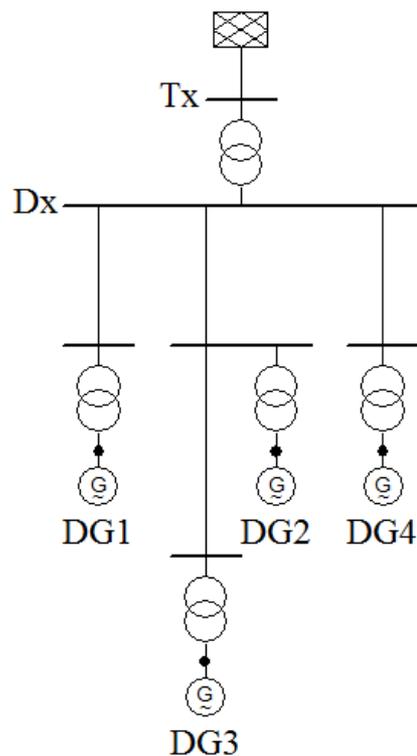
Response at different operating points (GE field tests)

Emulated Inertia Impact on Frequency Response

- Frequency nadir can be improved
 - Rate of change of frequency (ROCOF) issue may remain on small isolated systems

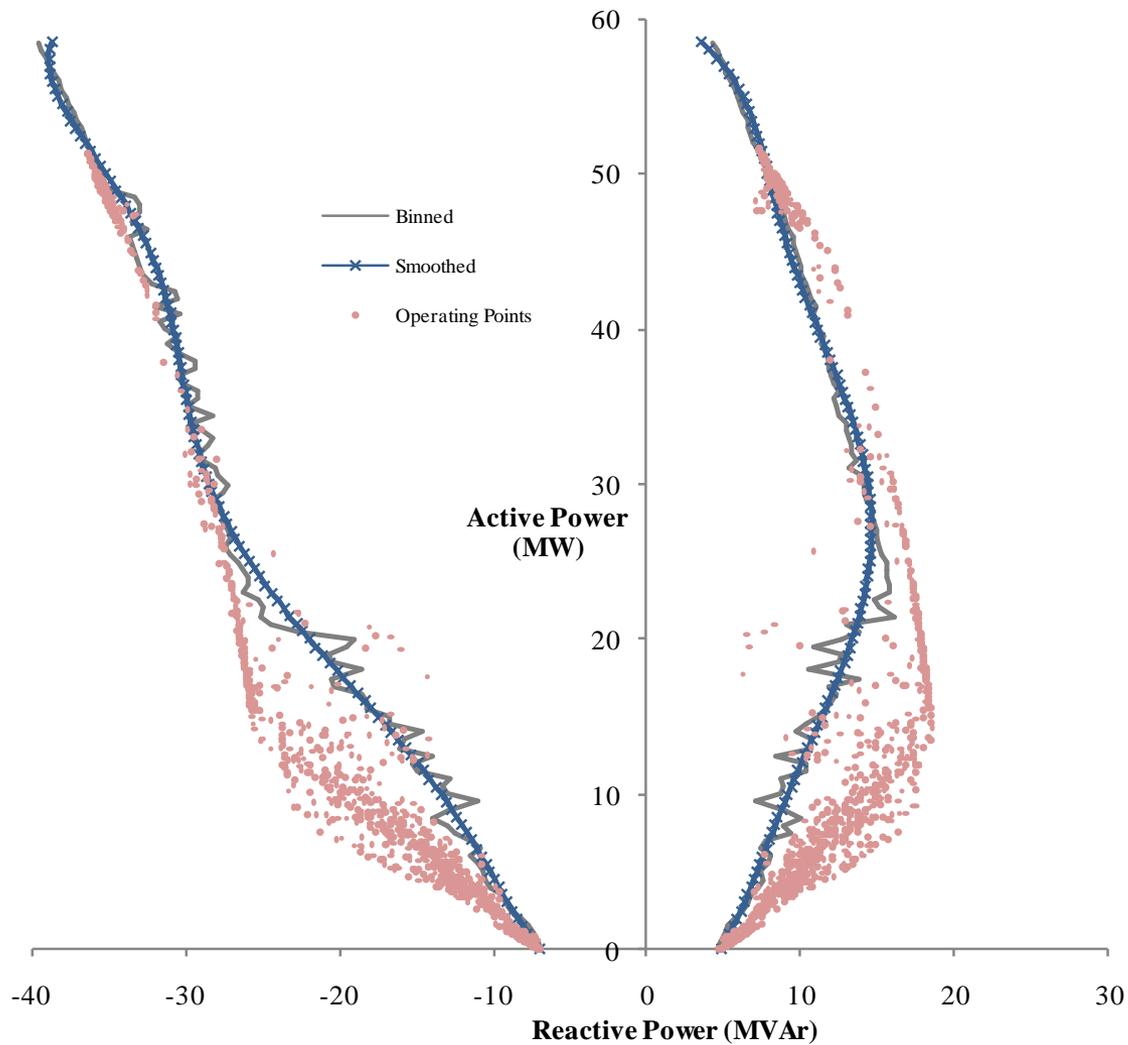


Energy Harvesting Networks (EHN)

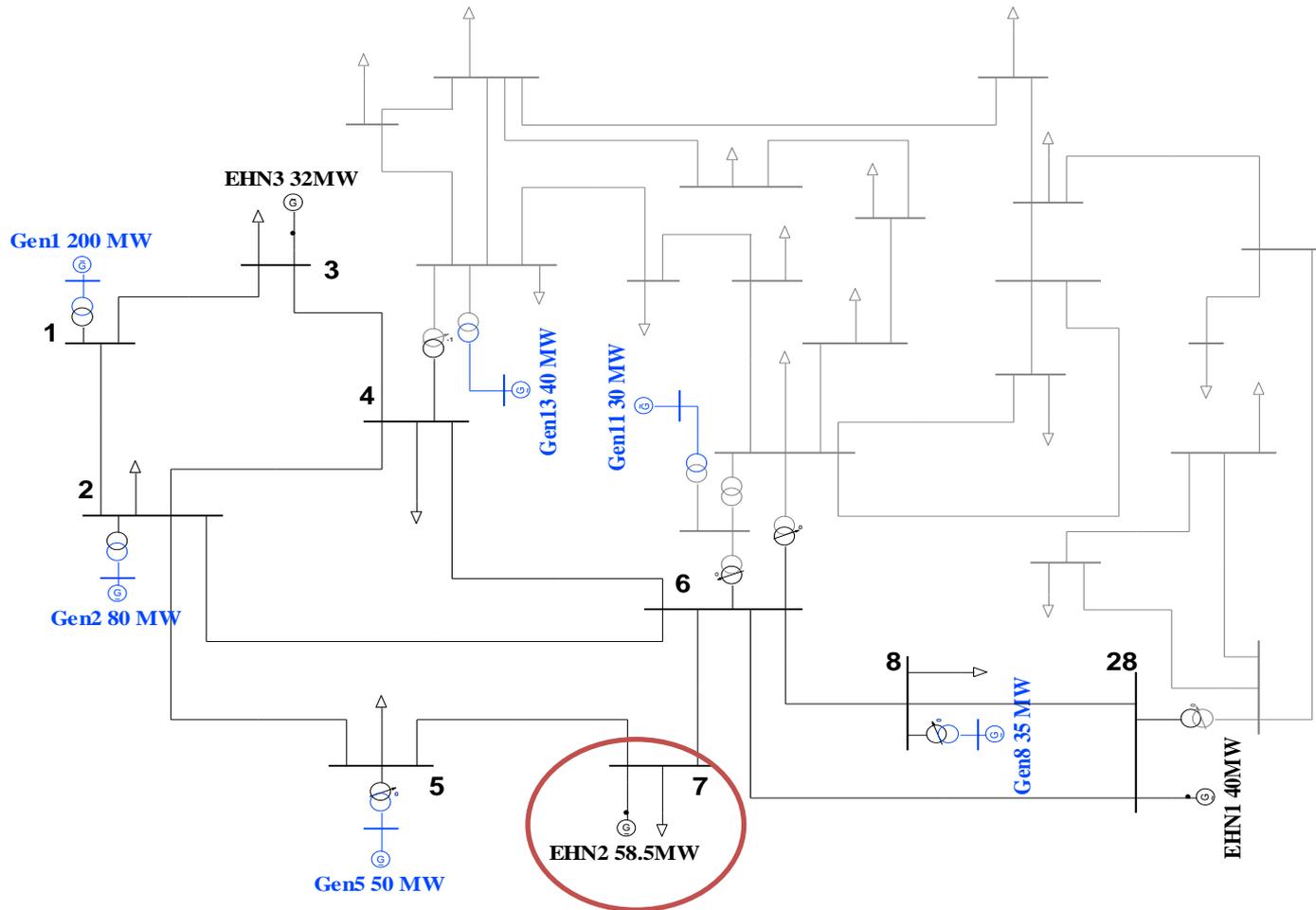


- Operate each generator to maximise export or import of reactive power
- Time-series load flow with historic generator outputs
- Record power flow at 110 kV node

EHN Capability

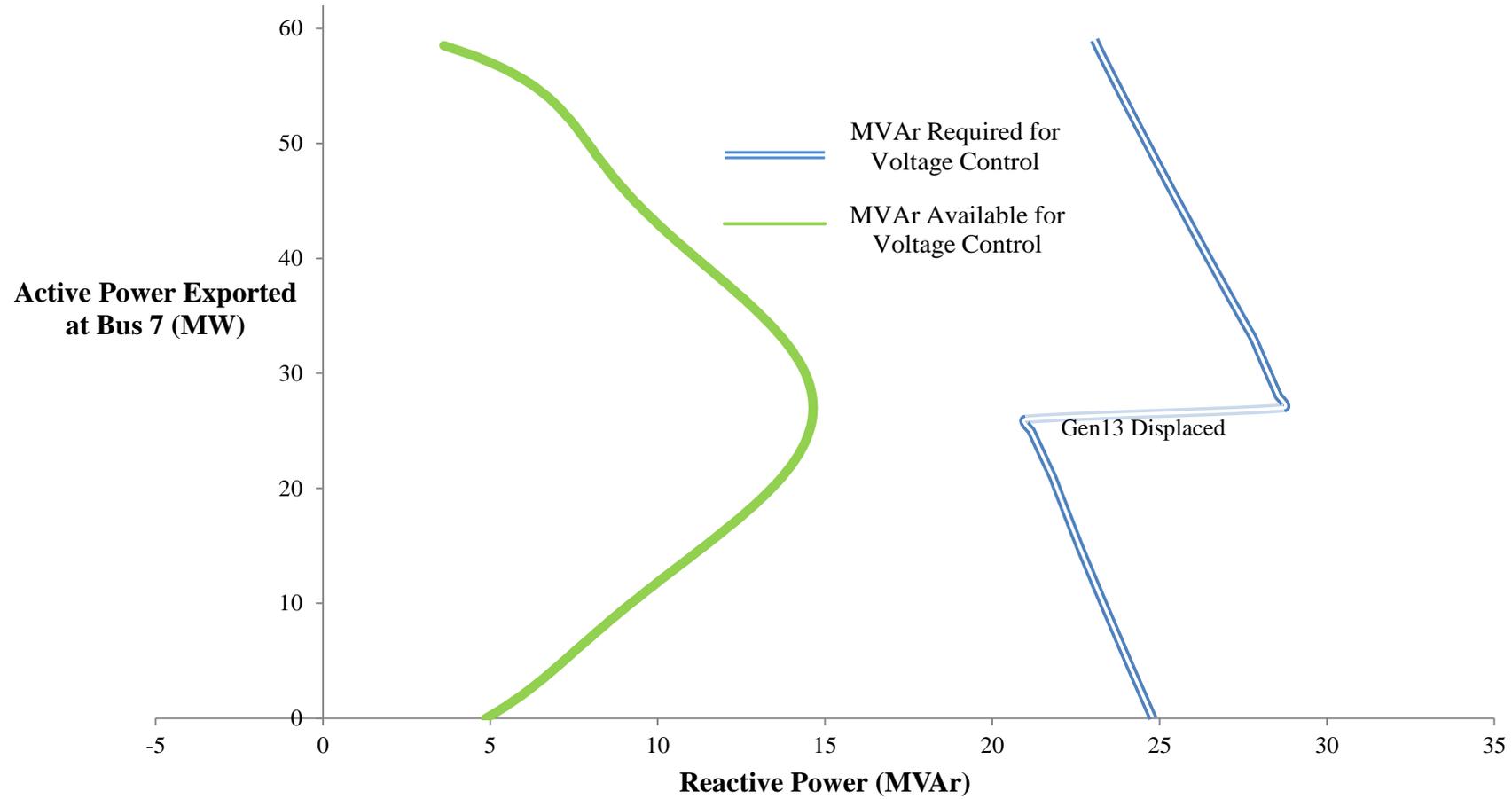


IEEE 30 bus test system



Planning Technique

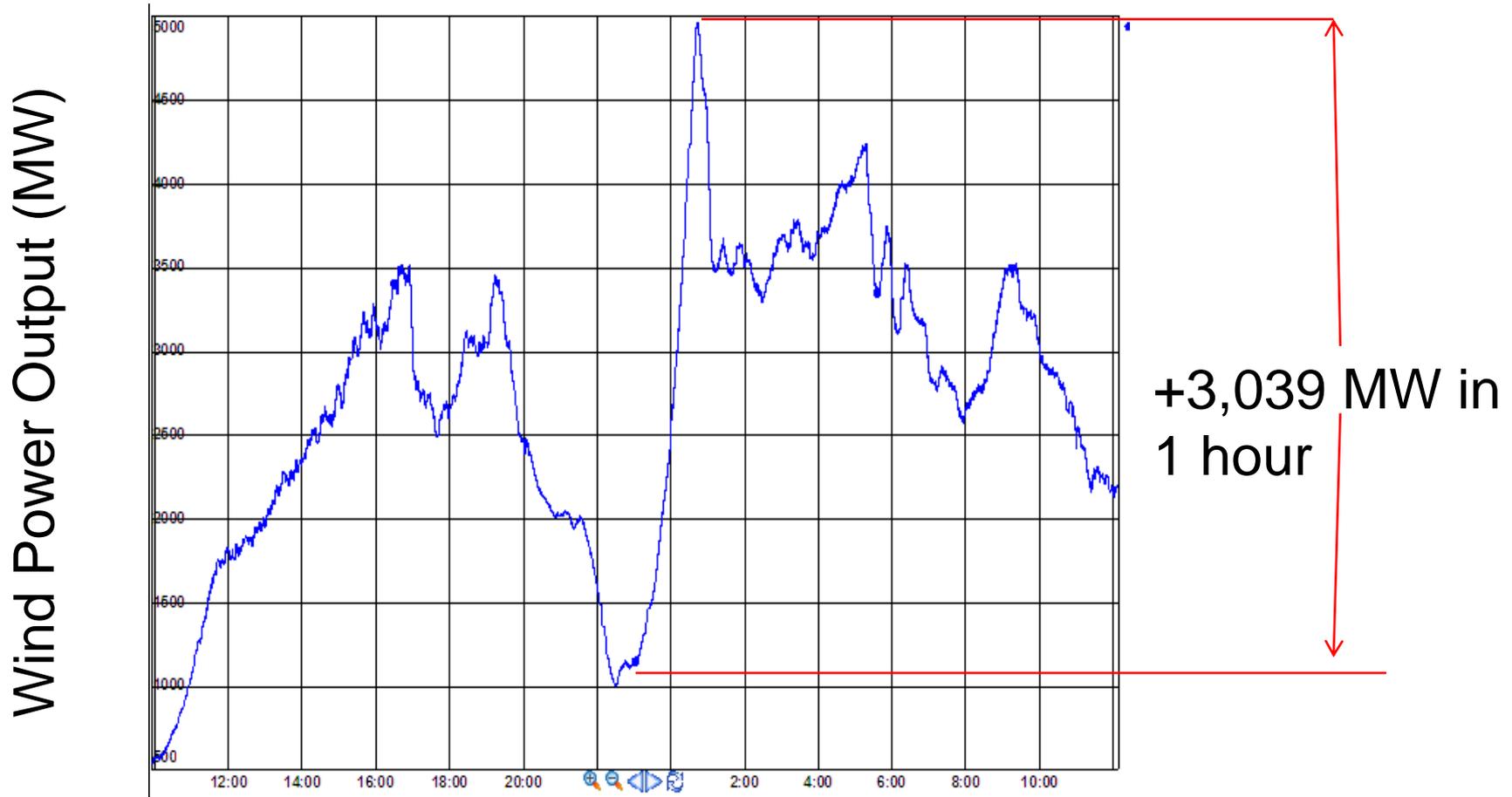
Voltage Control Needs at Bus 7





Flexibility

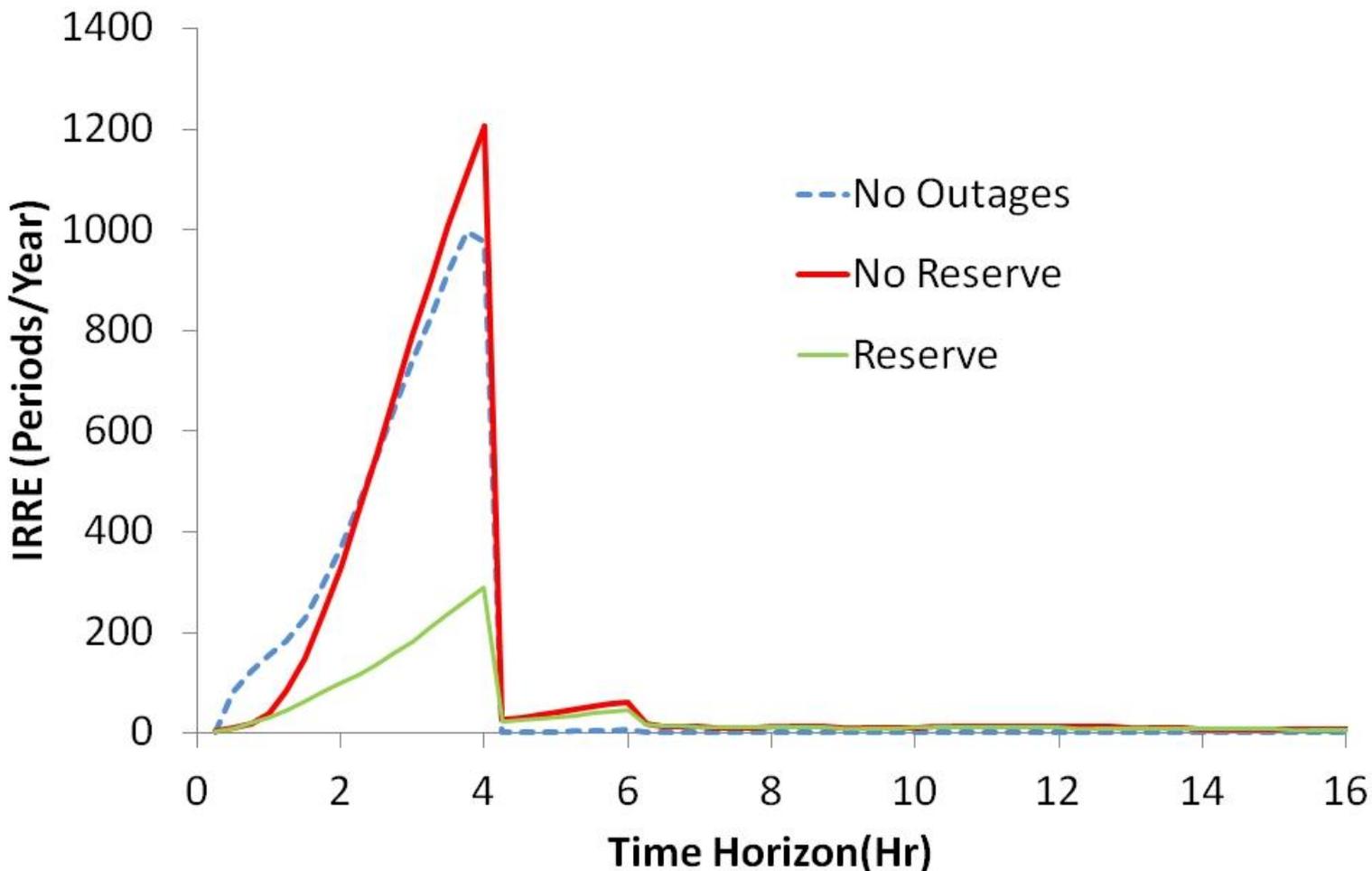
Ramp ERCOT - 18/19th April 2009



Portfolio



Flexibility metrics



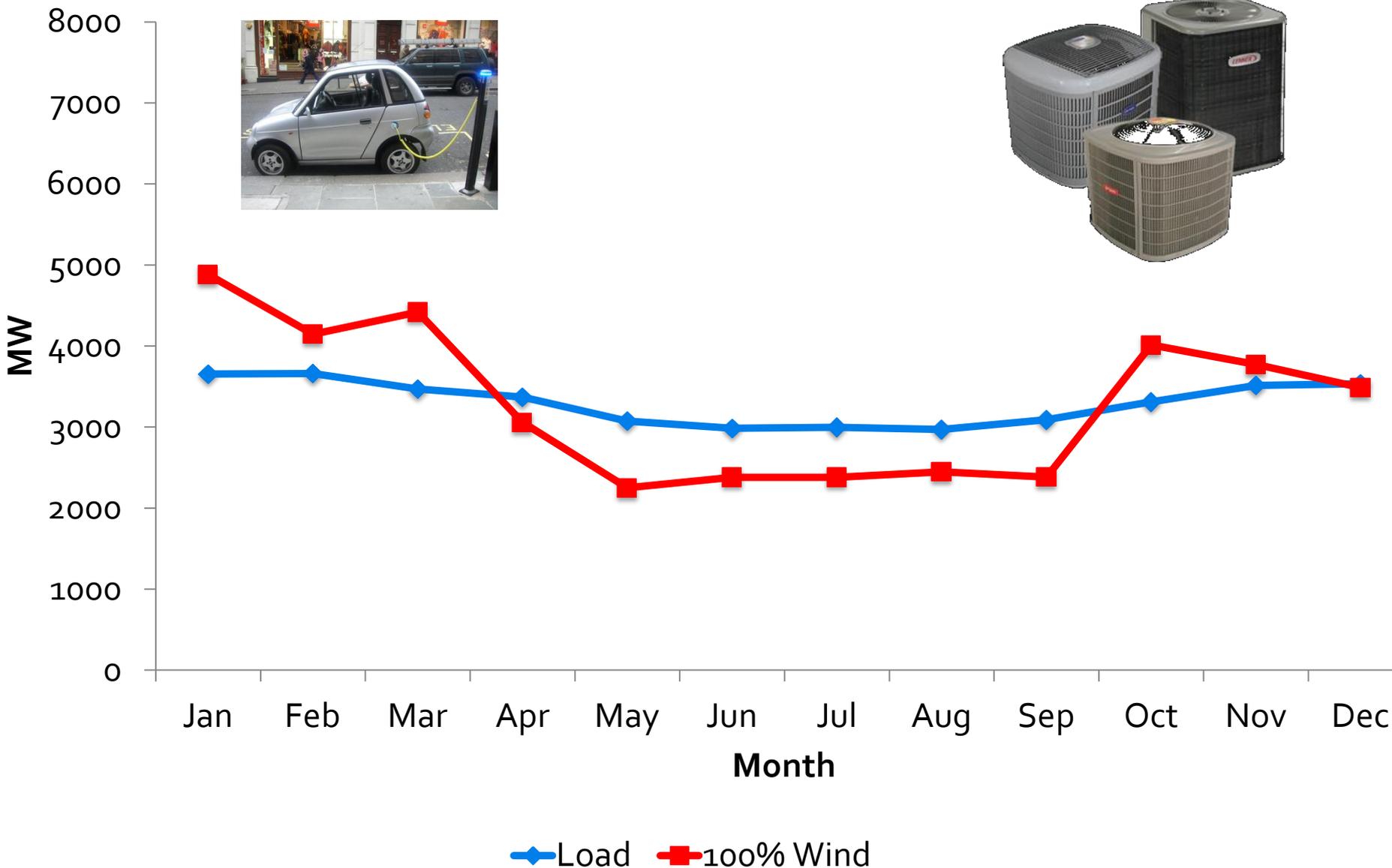
Lannoye, Flynn & O'Malley, *Evaluating Power System Flexibility*, IEEE Trans. Power Systems, Vol. 27, pp. 922 – 931, 2012.



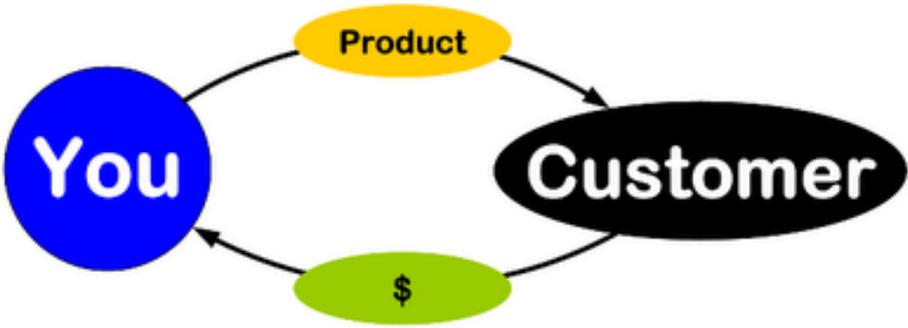
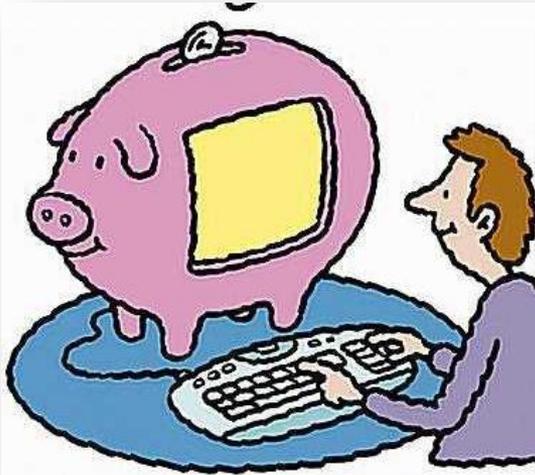
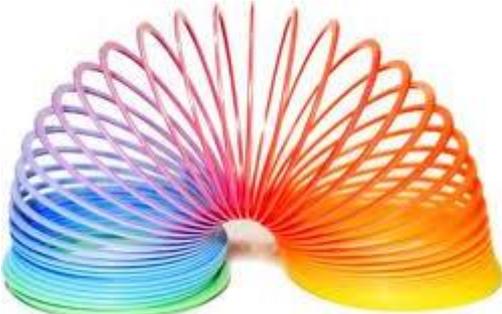
Load participation



Yearly Load & 100 % Wind



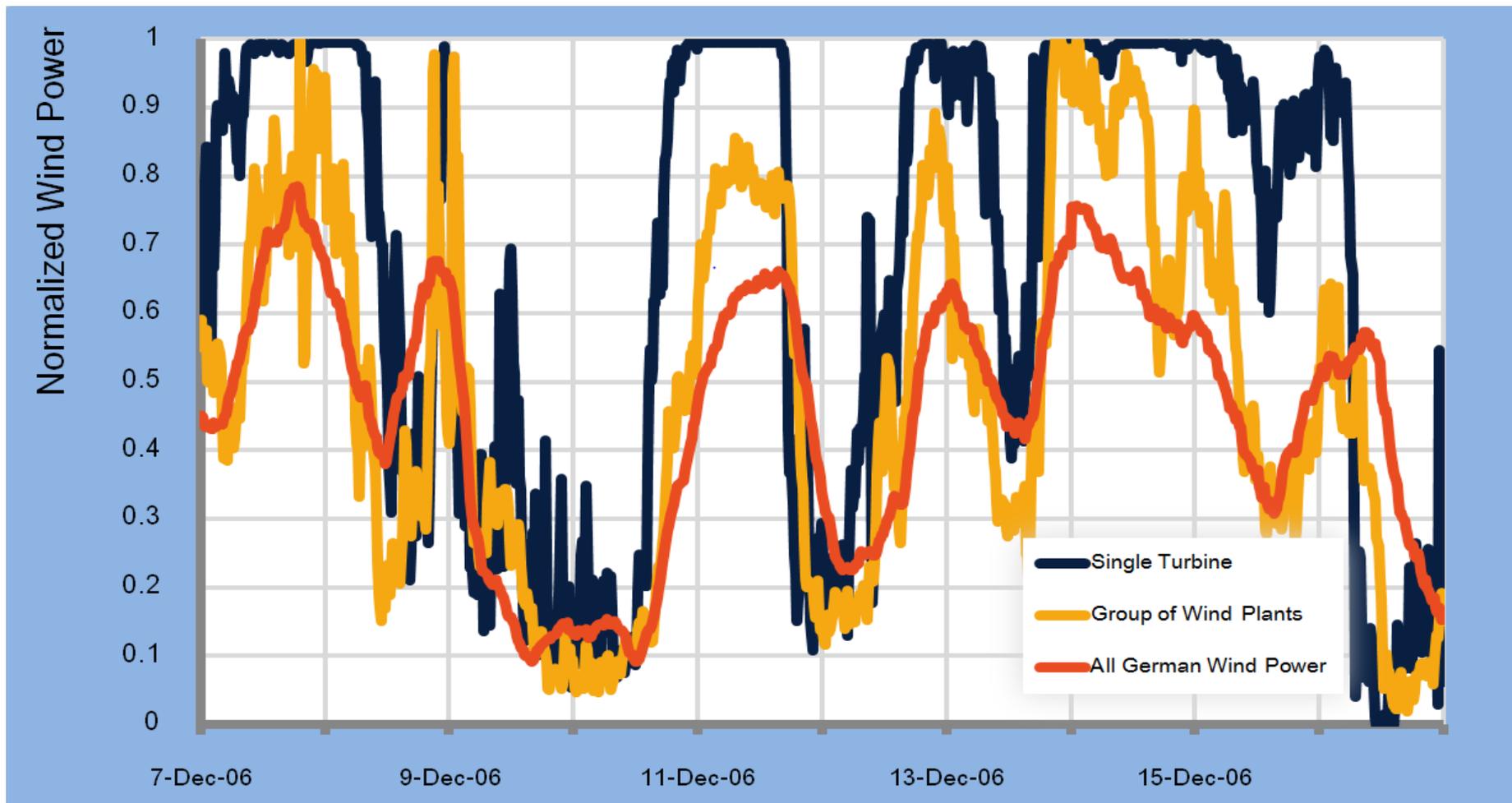
Business model





Transmission

Impact of Aggregation on Wind Variability



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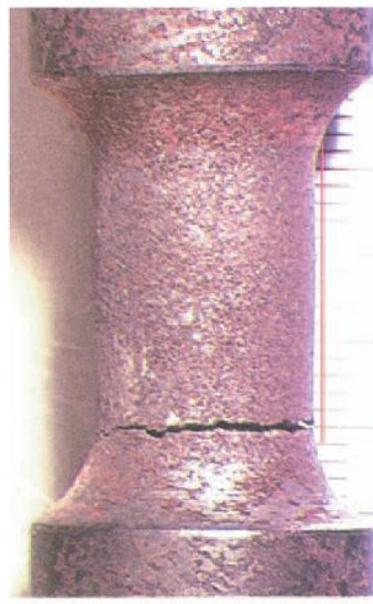
happytoast

Public Acceptance of Transmission

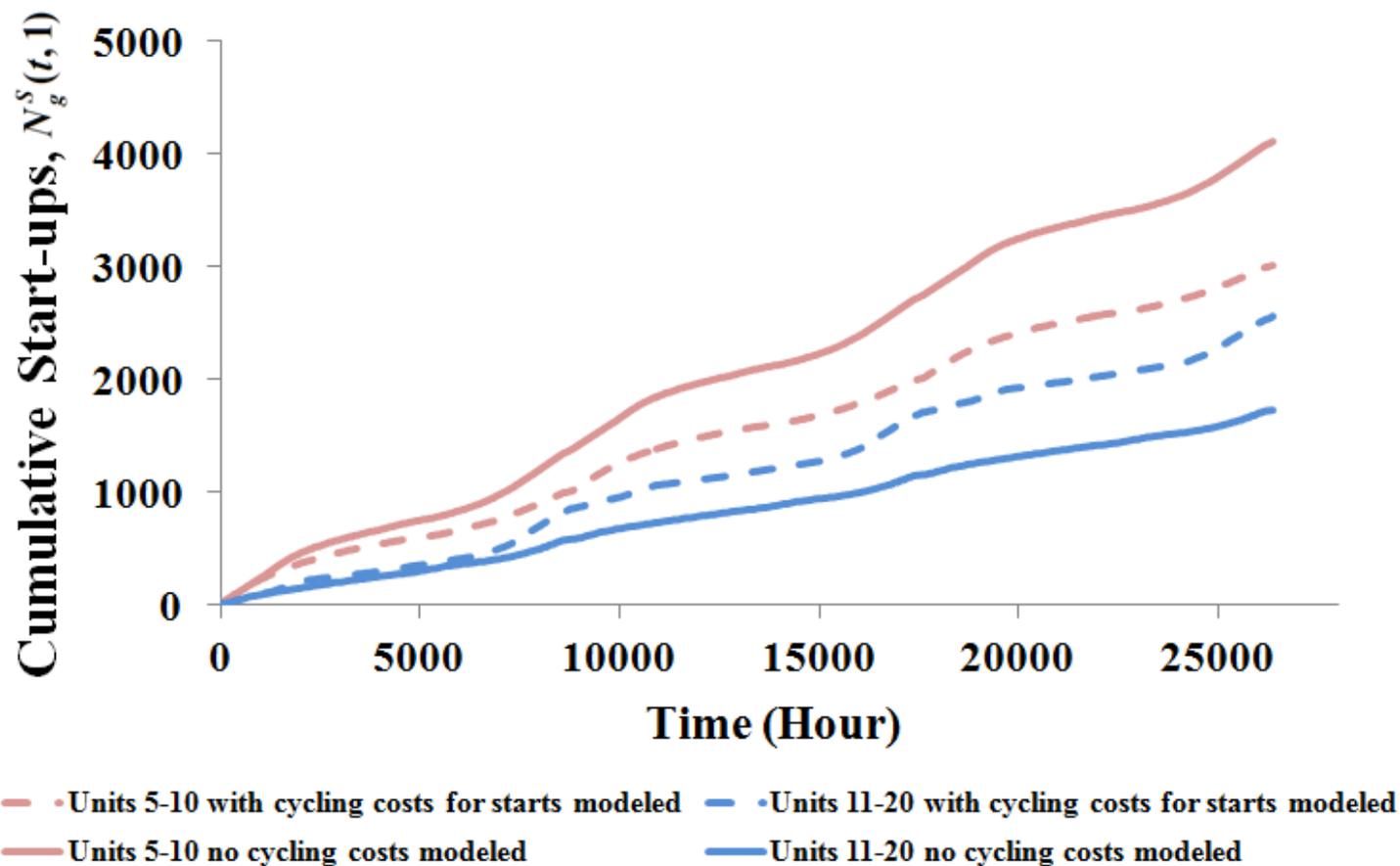


Cycling

Effects of Cycling

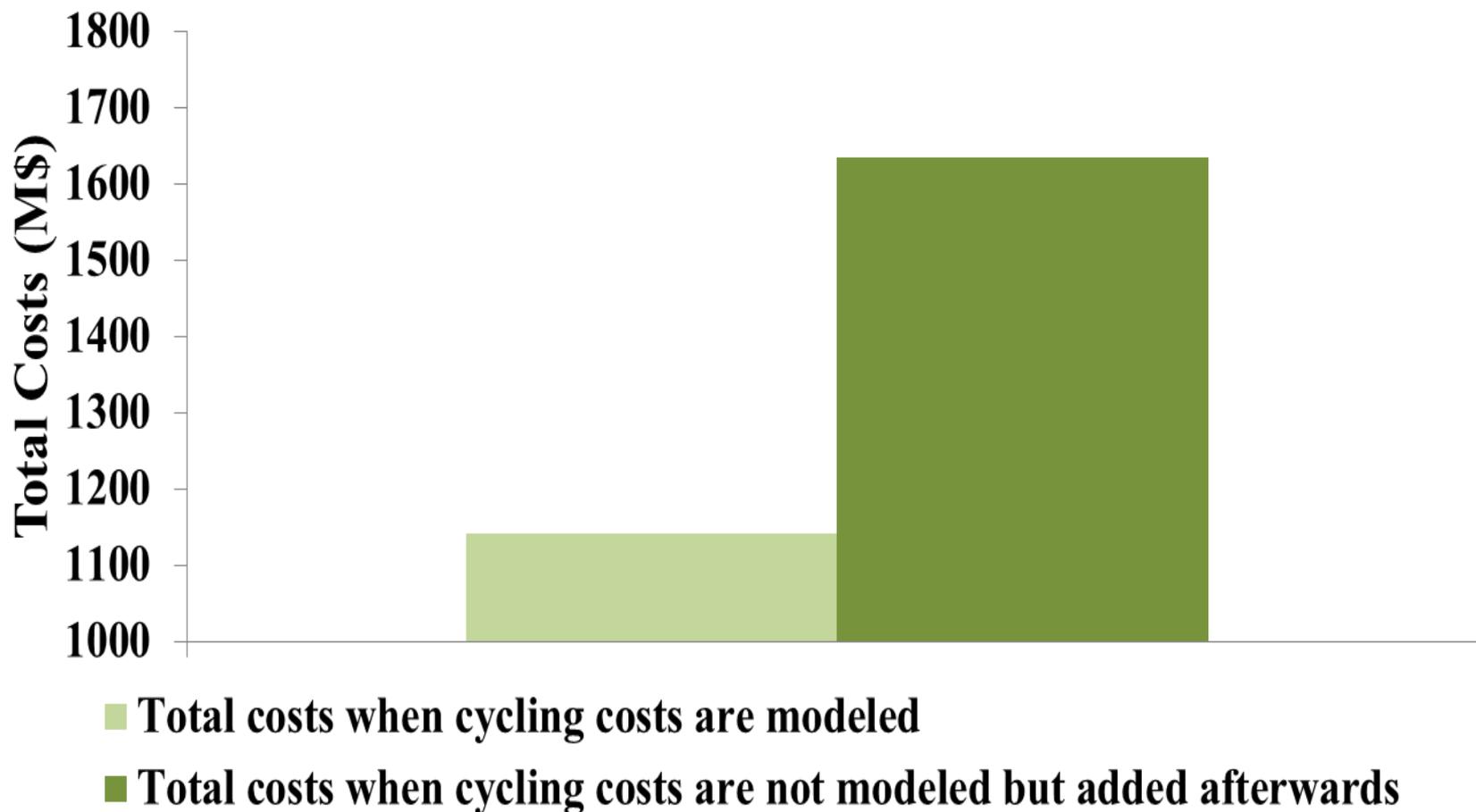


Impact of Dynamic Cycling Costs



Troy, N., Flynn, D., Milligan, M. and O'Malley, M.J., "Unit commitment with Dynamic Cycling costs", *IEEE Transactions on Power Systems*, in press, 2012.

Total system costs



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Recent Journal Publications

- Söder, L., Abildgaard, H., Estanqueiro, A., Hamon, C., Holttinen, H., Lannoye, E., Gómez Lázaro, E., O'Malley, M.J. and Zimmermann, U. "Experience and challenges with short term balancing in systems with large penetration of wind power", *IEEE Transactions on Sustainable Energy*, in press, 2012.
- Shortt, A., Kiviluoma, J. and O'Malley, M., "Accommodating Variability in Generation Planning", *IEEE Transactions on Power Systems*, in press, 2012.
- Burke, D., A. Tuohy and O'Malley, M. "Should Unit Commitment be Endogenously Included in Wind Power Transmission Planning Optimisation Models?", *IET Renewable Power Generation*, in press, 2012.
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